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A Quantitative Study of a Method for the Application and Control of a Pure Couple on a Posterior Tooth of a Rhesus Monkey

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**A QUANTITATIVE STUDY OF A METHOD FOR THE
APPLICATION AND CONTROL OF A PURE
COUPLE ON A POSTERIOR TOOTH
OF A RHESUS MONKEY**

by

Harold Y. Arai

**A Thesis Submitted to the Faculty of the Graduate School
of Loyola University in Partial Fulfillment of
the Requirements for the Degree of
Master of Science**

June 1966

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AUTOBIOGRAPHY

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CHAPTER I

INTRODUCTION

A pure couple has a certain physical significance to the mechanical engineer. It has the same significance to the orthodontist. What is unknown, however, is the biophysical changes it produces in bone. This research is aimed at the quantitative determination of how a pure couple attached to a bracket of a tooth will influence the periodontal environment of the tooth. The study of pure couples provides a means of understanding the complexity of forces involved in orthodontic tooth movement.

It is known that one of the fundamental objectives of a scientific investigation is that of making observations and measurements as accurately as possible. Orthodontics, as one of the biological sciences, has in the past placed great emphasis on the qualitative observations with the result that available quantitative or physical scientific knowledge has lagged far behind. This is especially true in the studies on tooth movement. Researchers in orthodontics oriented in the abstract physical sciences are now attempting to blend together the pure mechanical considerations with biologic principles in orthodontic tooth movement with the result that orthodontics is becoming a biomechanical science.

Orthodontic tooth movement is based on the application of a force on a tooth. The movement of a tooth produces changes of the biologic environment of a tooth through the medium of forces applied to the tooth. The process of moving teeth by means of force is biophysical. The biologic components are the tooth and its environment which includes various cellular elements in the periodontal ligament, the blood, the sensory organs, and the alveolar bone. The physical components are the orthodontic appliances which deliver forces to crowns of the teeth. Recent investigations have shown that forces applied to the crowns of the teeth are transmitted to the roots and produce a distribution of forces against the alveolar walls. It is these forces that determine patterns of alveolar bone resorption and apposition that make orthodontic tooth movement possible. Further, it has been demonstrated that there is an optimal range of forces in which tooth movements tend to be more physiologic in nature. There is much more to be learned about orthodontic tooth movements in relation to forces applied to the crowns of teeth, thus, further research must be directed toward this end.

In a scientific endeavor, a method must first be established. Once this is accomplished and all of the technical difficulties are overcome, the researcher can

study orthodontic tooth movement both qualitatively and quantitatively and come a step closer toward integrating the analytical sciences with the biological science of orthodontics.

CHAPTER II

STATEMENT OF THE PROBLEM

The purpose of this project is to devise a method for the application and control of a pure couple to the mandibular second premolar of rhesus monkeys. In this study, a predetermined force system will be used with calculated force magnitudes and direction. One half of the mandibular arch will be used for experimental movement of teeth and the other half will be used as a control. The teeth on either side will be taken out of occlusion.

The purpose of the force system is to tip the crown of the mandibular second premolar distally. This will be accomplished by a pure couple. A couple is a system of two forces acting upon a given body. These forces are equal, opposite and parallel but not collinear. They do not have the same action line nor the same point of application. In this study, each of these forces will be equal and opposite in a plane tangent to the buccal surface of the premolar tooth. The force nearest the occlusal surface is directed distally while the other force nearest the gingiva is directed mesially. When a pure couple is placed anywhere on the tooth, a center of rotation occurs at centroid.

The tipping movement that results under the influence of this force system will be studied by determining measurements of physical quantities. These measurements will be obtained from lateral and occlusal radiographs. A stereotaxic instrument will be used to position the animal while obtaining the radiographs. A rectangular coordinate system will be used to measure the movements of the teeth on the lateral and occlusal radiographs. The termination of the experiment will result when the appliance to achieve a pure couple has become deactivated.

CHAPTER III

REVIEW OF THE LITERATURE

The study of orthodontic tooth movement by orthodontic force systems has followed the pattern common to many scientific endeavors. First there was the period of observation of tooth movement. Before the advent of histologic and radiographic data, only theories were offered to explain the reaction to tooth movement by force application. Kingsley (1877), presented the compressibility and elastic theory. Based on Wolff's law of transformation, he stated that the compressibility and extensibility of bone made possible all the changes of the movement of teeth. Farrar (1888), explained tooth movement as a result of bone resorption on one side of the tooth and bone apposition on the other side.

Carl Sandstedt (1904-1905), was the first to study orthodontic tooth movements histologically. He used a labial arch wire affixed to the six maxillary incisor teeth of a fourteen year old dog. Bands, cemented to the canine teeth, were fitted with tubes arranged in a horizontal position through which the arch wire ran. The ends of the arch wire were fitted with threads on which there were little nuts. The nuts were tightened daily so the force

was continuous to the tubes serving to draw the labial arch lingually. The arch functioned to retract the incisors lingually while the canines were drawn mesially. To prevent occlusal interference from the lower arch, the canine tooth was reduced in size and devitalized. The duration of the experiment was three weeks and during this time, the crowns of the incisors were retracted lingually three millimeters. The extent of movement of the dog's teeth was determined by impressions of the jaw, photographs, and radiographs. He also examined the teeth in histologic cross-sections that were made after the animal had been sacrificed. He observed that teeth moved because of the biologic phenomenon of bone resorption and apposition with the tooth acting as a transmitter of force to the periodontal ligament, and the alveolar process. The process by which teeth were able to move through alveolar bone was called by Sandstedt "undermining resorption". Sandstedt described the mechanism on how the teeth had moved with his observation that the crown of the tooth had moved in the direction of the force while the apex of the root had moved in the opposite direction. He felt that the two opposing processes, appositional and resorption, in the different parts of the alveolus appeared to be in equilibrium with the center of tipping in the

middle of the root.

Talbot (1903), used dogs to study the pathologic changes accompanying tooth movements. The condition of the experiment was such that the rate of tooth movement was considered greater than physiologic. Prior to Talbot's experiment, Farrar (1876), in clinical observations established that physiologic tooth movement was in the range of $1/240$ th of an inch every twelve hours. Pathologic tissue changes occurred if the aforementioned value was exceeded. This was the rationale behind Talbot's experiment. He made German silver crowns for the maxillary canine teeth. Jackscrews were soldered on each side of the crowns and the teeth were moved $1/240$ th, $1/210$ th, and $1/60$ th of an inch respectively per day. The duration of experiment was two weeks. The significance of Talbot's work was an attempt to regulate teeth with controlled (unit) time and distance.

Angle (1907), in his textbook, tooth exception to Sandstedt's explanation. In his chapter dealing with tissue changes incident to tooth movement, he stated that there is very little displacement of the apex because of the greater resistance offered by the thickened bone in that area and by the innumerable fibers that encapsulate

the apex.

Oppenheim (1911), was the first to use primates to study orthodontic tooth movements. He used a spring arch with ligatures for a period of forty days and used the mandibular teeth as controls. Activation of the appliance was done every five days to move the deciduous maxillary incisors labially. His findings did not correspond with those of Sandstedt.

Oppenheim explained that his histologic preparations showed bone changes almost throughout the entire length of the root, decreasing in intensity from the alveolar crest to the root apex. He observed in the area of immediate proximity to the root apex no changes in the bone. He concluded, therefore, that the tooth moved like a single "one armed lever" with the apex of the root serving as the center of rotation.

Fish (1917), was one of the earliest investigators who studied biomechanics and its application to orthodontic tooth movements. He described a couple as "two forces which are equal and opposite and there is a distance between them". The action of a couple is purely rotative and this tendency is measured by the product of the force applied and distance. There can be no translative tendency of a tooth because the forces exactly balance each other except

for the tendency to rotate the tooth. He states, "that the effect of a couple is to move the apex of the root in a direction opposite to the applied force". He concluded that the point he called "the center of resistance existed somewhere between the apex and the gingival margin where there was no tipping or rotation of the tooth.

Case (1921), classified the action of tooth movement as lever arms. His appraisal of the explanation of tipping was based on the action of a second class lever. He concluded that the apex was displaced in an opposite direction to that of the applied force and that the center of rotation was located at the junction of the middle and apical third of the root.

Johnson, Appleton, and Rittershofer (1925), used three rhesus monkeys, ages five, three, and two years old, to study tooth movements. The three year old monkey was used as a control. The five year old monkey had a labio-lingual appliance placed on its maxillary teeth. An auxillary spring was soldered to the main lingual arch. A labial force of two ounces was exerted by ^{the} spring to the maxillary right incisor at its gingival margin. The experiment was conducted for twenty-six days. The two year old monkey had a similar appliance to that of the five year old monkey, but the force of its spring was $1 \frac{5}{8}$ ounces.

This experiment lasted for forty days. Both experiments demonstrated resorption and deformation of the root at the apex. In addition, they described the nature of tooth movement as a tipping action in which the crown moved in an opposite direction to that of the root apex. Their research demonstrated the tooth was moved like a "two armed lever" and the position of the fulcrum was in the middle of the root.

Bodecker (1925), commenting on the contradiction between Oppenheim and Johnson, felt that the degree of pressure was the reason that the bone was not any more resistant between the gingiva and the upper third of the root than it would be lower down at the apex.

Schwarz's (1928), early studies on orthodontic forces were done on rhesus monkeys. He applied horizontal and oblique forces and analyzed the tipping effect of the tooth in the alveolus. He found that in the tipping movement of a single rooted tooth, the center of rotation "lies somewhere in the apical half of the clinical root, and nearer to the middle of the root than the apex".

Kronfeld (1931), confirmed the results of Schwarz's experiment by studying histologic sections of human teeth made from the jaws of a thirty-eight year old man shortly

after he died of peritonitis. He made precise measurements of the widths of the periodontal spaces and showed that a tooth exposed to a strong horizontal tipping force had the minimum width at the middle of the alveolus and more than double the width toward the upper and lower ends of the root. Kronfeld felt that this fact pointed out the precise location of the fulcrum of a moving tooth to be in the middle of the root.

Schwarz (1932), later applied known force magnitudes to tip premolars of dogs in a buccal direction. His first series of experiments was done with recurved springs. A lingual arch was placed on the mandibular teeth of a young dog. The first molars and canines were banded and on each side of the arch a recurved spring was soldered to the lingual arch wire. The spring lay along three of the four premolars of the mandibular arch. The springs were bent in order to direct the knee of the spring mesially on the right side and distally on the left side. A force of 3-5 grams was directed on the free end, of 17 grams in the middle and of 67 grams on the knee of the springs. The experiment was conducted for five weeks. The spring was reactivated at the end of the second week. The results revealed a difference between the free end and the knee of the spring.

The force of the free end was continuous and gentle and the vitality of the periodontium was not effected. The knee of ^{the} spring revealed a strong force which endangered the vitality of the periodontium. There was evidence of rapid resorption and jiggling on this side of the spring.

Schwarz next conducted an experiment on another young dog using a loop spring on the maxillary teeth. A lingual arch was fixed to first molar and canine bands and a loop spring was soldered to the lingual arch. The spring moved the three premolars buccally and exerted a force of 20 to 25 grams. The experiment was conducted for two and one half weeks. The histologic findings were similar to the free end portion of the recurved spring. Schwarz concluded that 20 to 25 grams per square centimeter of root surface can bring about tooth movement without damage to the periodontal tissue.

Marshall (1933), completed a study of bone and tissue changes incident to experimental tooth movement and its application to orthodontic practice in Macaque rhesus monkeys. Marshall observed that the teeth of monkeys correspond to those of man in shape, position, and attachment and are all more similar to the human than those of other available experimental animals. He concluded that

excessive pressure resulted in not only the resorption of bone but also root resorption.

Orban and Gottlieb (1936), raised the bite of dogs by means of crowns, this enabled them to study the periodontal space under stress. The stages of the experiment ranged from 12 hours to more than a year. In this manner, they would systematically observe the development or subsidence of all changes. They confirmed Schwarz's findings that in the case of gentle forces, the axis must be physically exact in the apical third of the root and only if the apical fiber apparatus is especially developed, could it be displaced from this point a little in the apical direction. When strong forces are used, the tooth will be pinched in the alveolus rather diagonally, its "tilting axis being in the middle of the root". Orban then stated that "in all my histologic examinations, I never saw the motion center at the apex".

Stutteville (1937-1938), in a series of experiments in which forces were applied to the teeth of human beings, found that changes took place in the supporting tissues surrounding the teeth. The method of moving the teeth was accomplished by means of an auxillary spring attached to either the lingual or labial arch wire. In a single tipping experiment, he reported that the resorbed areas

are at the alveolar crest on the pressure side and on the apical surface on the opposite side of the root. Secondary resorption is produced on the root surface in areas diametrically opposite to the area of primary resorption. The secondary resorption results from jiggling that is caused by forces of the inclined planes during mastication. In addition, Stutteville listed conditions that control tooth movement (1) crown to root ratio; (2) shape and number of roots; (3) condition of the alveolar bone as it is determined by the function of the teeth; (4) the hourglass shape of the periodontal membrane; (5) the distance through which the force is active; (6) the amount and direction of the force.

Skillen and Reitan (1940), used dogs to assess the factors influencing the rotation of teeth. Three types of appliances were used to rotate the maxillary right and left second incisors of the dog. In each instance, the arch wires consisted of .018 inch diameter wire. The first appliance used was a metal spring ligated by a stainless steel wire between the loop of the spring and a lingual staple on both incisors. The second appliance used a ligature wire passed directly from the lingual staple to the arch wire. The third appliance consisted of two springs ligated by stainless steel wire to the

staples on the labial and lingual surfaces of the teeth. Skillen and Reitan then placed forces ranging from 9 gms. to 250 gms. for time periods of three to thirty-seven days. In addition, he predetermined the total distance the appliances were to exert their force. These studies revealed that both the first and second appliance resulted in a tipping action concomitantly with rotation. The third appliance resulted in a rotational action with little tipping. The significance of this study was the correlation of the factors force, time, and distance through which a tooth moved.

Breitner (1940), used Macaque rhesus monkeys to ascertain changes resulting from orthodontic treatment. The changes were noted clinically and the animals were subsequently sacrificed for histologic study. Changes were found in the alveolar bone surrounding the posterior teeth, the angle of the jaw, and the temporomandibular joint through the evidence of bone resorption and apposition.

Bunch (1942), used one year old dogs to demonstrate tissue changes following the depression of teeth. The maxillary and mandibular second incisors of the dog were used. An onlay, cemented on both of the mandibular second molars opened the anterior vertical space approximately 5 to 6 mm., thus, it is assumed all tooth movements were

induced by the appliance. The appliance consisted of a labial arch with auxillary springs. The total time of the experiment was from twenty-eight to thirty-five days with forces ranging from 48 gms. to 69 gms. with the result an average 1 mm. of depression occurred. The significance of this experiment was the attempt to correlate the force applied, the distance through which the force acted, and the time interval between adjustments.

Oppenheim (1942), investigated specimens of human teeth that had been subjected to various orthodontic force systems from periods ranging from one to three years. The teeth had been extracted for various reasons. Nine specimens were used in the study. The first two specimens were premolars that were orthodontically moved by means of a lingual arch and finger springs for periods of one to four days. Four specimens dealt with changes caused by silk and wire separation during a 24 day period. Two specimens were subjected to three years of treatment with a lingual arch and intermaxillary elastics and the last specimen was a tooth treated with the edgewise appliance for one and a half years. Oppenheim considered the reaction of the periodontium to the different degrees of force. He measured the amount of root resorption by means of histologic cross-sections. His results point out the fact that there should

be an avoidance of applying too great or too long of a compressive force on the periodontal membrane. He concludes that light forces and frequent rest periods result in less damage to the tooth.

Reitan (1947, 1951), reported animal experiments which investigated the changes occurring in the supporting tissue of teeth which were moved bodily by means of a continuous force. He moved the incisors and premolars of dogs by means of a coil spring force of 58-85 grams on the premolars and 35-55 grams on the incisors. The appliances were reactivated every two weeks for a period of 47 days. The teeth in the experiment were moved bodily as indicated by the even tension on the periodontal fibers all along the root surface. As a result, when force magnitudes were maintained within a certain limit, pressure areas were not created to the same degree as on teeth which tipped. Reitan concludes: when light continuous forces are used to move teeth bodily, root resorption did not occur. The same forces or even lighter forces when used to tip teeth would result in root resorption. He further states that all teeth moved bodily were displaced more coronally than in the apical portion of the root. This he ascribed to the mechanical resistance created by the teeth with long roots. Reitan revealed, in all instances, that

time was more of a factor than the amount of force applied during the initial stages of tooth movement. Significant variation in tissue reaction, for instance, occurred after a 36 hour period with a majority of the force magnitudes.

Reitan (1953), and (1958), compared tipping and bodily movement of teeth. He claimed that in a tipping movement the tooth acts like a "two arm lever". The active force is always greater than the force applied and the cell-free areas are concentrated in a small area near the alveolar crest. The tooth moved in a bodily motion has its force distributed over the entire surface of the root. Therefore, he states that the force exerted per square millimeter is greater in a tipping movement than in a bodily movement. He cites this explanation why areas of hyalinization are observed less frequently in bodily movement than in tipping with equally strong forces. Reitan recommends that 250 gms. be used in the continuous movement of a cuspid tooth.

Aisenberg (1948), comparing tipping and bodily movement of a tooth states that tipping is more of a common type of movement with light forces where only bundle bone is found on the tension side. Bone trabeculae were found to be built in the direction of the applied force with the application of a strong force. The bone trabeculae follow the course of stretched fiber bundles of the periodontal

membrane to prevent tearing. Aisenberg also mentions that the fulcrum in a tipping movement with a strong force is just below the center of the alveolus while with light forces the fulcrum appears more apically.

Frey (1948), discussing the position of the fulcrum in a single rooted tooth when subjected to a tipping movement, stated that it would be "near the junction of the middle and apical third of the tooth". Frey found two areas of tension and two areas of pressure as the tooth moved in the tipping movement. In the bodily movement of a tooth the fulcrum was positioned in the region of the apex of the root, when remains stationary.

Moyer and Bauer (1950), studied the periodontal response for various tooth movements. They reproach the orthodontic profession for its reliance on mechanical means for moving teeth. They state "while we speak loosely of what one appliance will do and what another is unable to achieve, we would be more correct to speak of what the periodontal membrane will allow one appliance to do and what it deters another". Moyers and Bauer state that most of the orthodontic movements were tipping procedures where the membrane is crushed just above the apex of the root on one side and at the gingival crest of the alveolus on the other side. In addition, they feel that it is

fortunate that most orthodontic movements are tipping procedures for they believe the membrane recovery is faster and the chances of permanent injury are less in this movement than in most others. They conclude that their study reveals that there are three factors which result in changes in the periodontal membrane. First there is the amount of force, its sheer weight in grams or ounces; second is the distance the force is active; and third the length of time the force is applied. Speaking of force values, Moyer and Bauer state that ideally an appliance should operate over a distance of less than 0.2 mm. with a force between 15 and 25 grams.

Storey and Smith (1952), performed an experiment with forces in orthodontics and their relation to tooth movement. In the experiment, they used five patients ranging in age from 12 to 15 years old who required the distal movement of the cuspid teeth. To retract the cuspid, a light spring was placed on one side of the dental arch and a heavy spring was placed on the other side. The heavy springs were activated to apply known loads from 400-600 grams and the light springs were activated to apply known loads from 175-300 grams. To apply these known forces, the springs were calibrated by determining load deflection curves. In addition, reference marks were placed on the

appliance corresponding to the deflection for various loads. The first molar and the second premolar were used as anchor units for the springs to move the canines distally into the first premolar extraction site. The comparison of the clinical results of the two springs were done by a direct means of measurement. Weekly direct measurements were made by means of a needle pointed calipers which were accurate to 1/1000th of an inch. The distance from the reference point to a point on the anchor unit and to a point on the cuspid were measured. The change in the measurements was used to determine the new value for the deflection of the springs. The spring had a known deflection load curve thus the new value of the load could be determined. Similar behaviour of the teeth was noticed in all five patients studied. With the light springs, movement of the teeth occurred rapidly after the initial activation to the range of 175-300 grams. This continued until the force had decreased to a value which varied from 135-180 grams for the five patients. Movement then either ceased or continued at a very slow rate. In the case of the heavy springs, which were activated to higher values of force, initially very little or no movement of the canine occurred. Instead the anchor unit moved until the force applied by the spring had decreased to

200-300 grams. Then the movement of the anchor unit stopped and the cuspid started to move giving the same behaviour as found in the cuspid that was moved by the light springs. Storey and Smith state that the optimum range of force values which should be used to produce a maximum rate of movement of the cuspid tooth without movement of the anchor unit is from 150-200 grams. They also found that the cuspid tooth always moved by tipping approximately about the apical one-third of the root. This means that the pressure between the root of the tooth and the bone varied from a maximum value at the alveolar margin to zero at the center of tipping.

Jarabak (1960), gave tangible values to the term "light forces" and "heavy forces". Prior to this time, these terms were subjective evaluations of forces by different operators varying from operator to operator. A "light force" is one in the order of one to four ounces (27.7 gms. to 110 gms.). A force in the intermediate range is from five to six ounces. Orthodontic forces beyond six to seven ounces have shown to be excessive and result in a decreased rate of tooth movement.

Storey (1953), reported radiographic interpretations in his experiment conducted on cuspid teeth which were moved distally using cuspid retraction springs of known

deflection loads characteristics. He reported that there is significant difference in the behaviour of bone surrounding a tooth following the application of forces of varying degrees. With low forces, dense laminated bone is formed in the tension area and the trabeculae were arranged in the direction of the force. With heavy forces, bone laid down is less dense and can be differentiated from the lamina dura while the trabeculae are not oriented in the direction of the applied force.

Masseler (1945), roentgenographically studied the changes in the lamina dura during tooth movement. He found that during orthodontic tooth movement the lamina dura becomes much thicker and characteristically radiopaque on the side of new bone formation (tension side). The side of pressure shows a disappearance of the lamina dura during orthodontic tooth movements. He concludes that the thickness and degree of radiopacity of the lamina dura in the x-rays could be used as a diagnostic aid to indicate the duration and amount of tooth movement.

Halderson, Johns and Moyers (1953), investigated the variation of the forces directed upon a tooth by changes in the length and size of auxillary springs. They found that heavy forces interfere with circulation and cannot help but cause tissue pathosis. They also found that using

a series of light round wires to start edgewise appliance treatment causes tipping and the forces are much lighter than it is possible to achieve with a standard edgewise wire.

Macapanpan (1954), using the molars of 35 albino rats to determine the location of the fulcrum in a tipping tooth movement found that the fulcrum in the rat's molar was situated in the alveolar bone beyond the apex of the root. She determined the position of the fulcrum from changes in the periodontal space. She concluded by saying that "the variation in curvature, length, strength, and divergence of the root", were possibly responsible for the great variation in the distance of the fulcrum.

Waldo and Rothblatt (1954), devised a method for the study of tissue changes resulting from tooth movements in the rat. An elastic was placed between the first and second maxillary molar of the laboratory rat. The animals were sacrificed after three days. The nature of the tooth movement was a combination of tipping and bodily movement. The fulcrum point in the tipping movement appeared to be close to the apex in most of the animal teeth studied.

Huettner and Young (1955), performed an experiment to observe and compare structural differences following the orthodontic movement of vital and devitalized teeth

in the rhesus monkey. Three monkeys were used in the experiment that were three to four years of age. The edgewise technique was employed for the movement of the teeth. Coil springs (.007"), exerting a force of two ounces were used to move the anterior teeth in the maxillary and mandibular arches. Radiographs, photographs and models were taken prior to and after the experiment to ascertain the movement of the teeth, and these were correlated to histologic cross-sections. The experiment on the rhesus monkey demonstrated there was no difference between orthodontically moved vital and devitalized teeth in their gross and histologic aspects.

Huettner and Whitman (1958), used ten rhesus monkeys ranging in age from three to six years to study different types of orthodontic tooth movement. Using the edgewise appliance, they reported that, (1) continuous pressure of two ounces delivered by a coil spring to move the cuspid distally for a period of twelve weeks resulted in having the apex remain constant while the crown had been tilted distally for 8 mm.; (2) in tip back movements the fulcrum was in the middle third of the root; while (3) in buccal-lingual torque the fulcrum was located approximately at the alveolar crest. They concluded that several factors determined the position of the fulcrum, namely, the type,

amount, and direction of the force applied to the teeth and the physiologic reaction of the supporting tissues.

Wentz, Jarabak and Orban (1958), reported an experiment on tooth jiggling on six rhesus monkeys, about four years of age. They created cuspal interferences in a bucco-lingual direction by designing an orthodontic force system which would cause traumatic occlusion. The upper right second premolars had gold crowns placed on them and these were prepared in such a manner that the buccal cusp and its incline plane was exaggerated. An orthodontic palatal arch wire was devised and fitted, utilizing the upper right and left second molars for anchorage. A small finger spring was soldered to the arch wire and adjusted to engage a hook that was soldered on the lingual surface of the gold crown. The finger spring was activated to exert two ounces tension when engaged into the palatal hook of the crown. The tension in the finger spring upon the gold crown tended to pull the tooth to the lingual side each time the animal opened his jaw and disto-occluded his teeth. This arrangement produced a bucco-lingual jiggling trauma. The experiments lasted three days, two weeks, three weeks, three months and six months, respectively. Histologic cross-sections were made and assessed.

Clinically, a widening of the periodontal ligament

space resulted and extreme tooth mobility. The significance of this experiment points out the importance of analyzing force systems and design of proper orthodontic appliances which will avoid tooth jiggling.

Myers and Wyatt (1961), were the first to use the hamster as an experimental animal to study tooth movements. Their objectives were twofold. First they sought to test the feasibility of using the hamster as an experimental animal and secondly they evaluated their appliance ability to produce a continuous mesial movement of the hamsters mandibular first molar.

In comparison to the often used rat as an experimental animal, the hamster's root morphology was found more favorable for the "interpretation of the direction of force, and hence, the areas to which a tissue response could be anticipated". The appliance consisted of orthodontic bands on the mandibular first molars and the mandibular central incisors. Lingually a small eyelet was soldered on the bands. A retraction coil spring was constructed of 0.009 inch stainless steel wire, consisting of thirteen turns. The coil spring passed through the lingual eyelet on the molar and central incisors. The retraction coil spring was activated to produce four ounces of applied force to the first molar. The authors concluded that their

orthodontic appliance which they designed achieved a constant mesial movement of mandibular first molar. It was the desire of the authors to produce an appliance where future investigators could use different force magnitudes per unit time on the same species of experimental animal and thereby better understand orthodontic tooth movements.

Gantt (1960), Kemp (1961), Steir (1962), Krvavica (1963), and Follico (1964), employed teleroentgenograms in their studies of the movement of the mandibular first molars which served as anchor units during orthodontic treatment. These investigators evaluated dimensional changes in the periodontal space and lamina dura as shown on intro-oral roentgenograms. A headspanner for the orientation of the head was adapted and attached to cephalometric apparatus in order to prevent distortion errors due to the movements of the subjects head. This allowed the operator to replace the subject into the headspanner in the same spatial relation to the roentgen ray tube each successive time a record was taken. The roentgenograms were superimposed individually over each of its follow up films in subsequent series in order to ascertain dimensional changes in the periodontal space and lamina dura.

Gantt and Kemp reported that during the uprighting of the molar teeth using the Loyola University Light Wire

technique, the most prevalent movement of the anchor teeth was simultaneous extrusion and distal tipping. The center of rotation was found to be near the apex or middle one-third of the distal root. The mesial root elevated due to forementioned axial change.

Krvavica, studying the same patients and same teeth as Gantt and Kemp during the reduction of the Class II molar relationship and space consolidation, found the predominant tooth movement was mesial migration of the crown on the average of 1.28 mm. and .57 mm. of the roots in extraction cases and 1.04 mm. of crown and .66 mm. for roots in no-extraction cases.

Steir (1962), employing the Tweed Edgewise technique found that the mandibular first molar during anchorage preparation were tipped distally far less than the roots mesially. The axis of tipping was located within the cervical one-third of the two roots near the cemento-enamel junction.

Cushing (1961), performed an animal experiment on the laboratory rats. The bodies of the scapulae in laboratory rats were subjected to continuous pressures by means of small pairs of magnets encased in acrylic. The pressures studied ranged from less than 11.5 gms/cm² to 68 gms/cm² and the experimental time was from one to three

weeks. The characteristic repair reaction and bone necrosis occurred in the intervening plate.

Burstone (1962), states that the center of resistance in a single rooted tooth with a parabolic shape is at a point 0.4 times the distance from the alveolar crest to the apex. The center of resistance coincides with the centroid which in this case is the geometric center of that part of the root between the alveolar crest and the apex. With the application of a pure couple placed anywhere on the tooth, he states the center of rotation occurs at the centroid of the tooth, with the crown displaced in one direction and the apex in the opposite direction. Burstone states then that "it can be seen that, the center of rotation is located at the level where stresses are zero". Pure translation, which is described as bodily movement with the center of rotation at infinity, and pure rotation, where the center of rotation is at centroid are two basic types of tooth displacement.

Kulis (1962), in a clinical study of fourteen patients investigated the relation between the force magnitude and the center of rotation in the maxillary central incisors. He used force values of 53 gms. and 121 gms. and a radiographic interpretation and superimposition to determine the center of rotation. The results showed that there was

no significant difference in the centers of rotation when both forces were used. The teeth tipped about points apically at 1.2 and 1.3 mm. from the centroid of the root for the two groups studied.

Willian (1963), performed an animal experiment on five rhesus monkeys to study orthodontic tooth movements. His study observed clinically, cephalometrically, and microscopically the results of an anterior root spring on the maxillary central incisors, maxillary first molars and the associated periodontium of each of these teeth. The five test animals were subjected to continuous torquing moments applied to the maxillary central incisor for a period varying from nine to twenty weeks. He found on the basis of cephalometric evaluation, the greater the magnitude of the moment the greater the amount of tooth movement that occurred. The total movement of the apices of the incisors diminished with a decrease in the level of the moment. He also found that the incisors which were subjected to a heavy torquing moment showed considerable root resorption. In contrast, the incisors which were exposed to intermediate and light moments showed minimal root resorption.

Jarabak and Fizzell (1963), in their textbook systematically outlined the fundamentals of analytical mechanics and applied physics as related to tooth movements.

In the discussion of force systems, there is great emphasis on the combination of forces, and moments or couples. This was done by the authors because so much has been written in the past about orthodontic forces while the concept of associated moments has been repressed. They feel that the creation of one force applied to the crown of a tooth gives rise to at least one other force and often to a series of forces which are resisting forces developed at the roots. This fact, therefore, makes every force system include a moment of force or a couple.

Jarabak and Fizzell defined tipping as "turning of a tooth about any axis other than its long axis or one parallel with it". A tooth tips when adequate force is applied to it. The action line of that force does not pass through the centroid of the effective root area. It was observed and calculated that by proper amount of neutralization of a tipping moment, one can place the center of tipping outside the root. By complete neutralization of the tipping moment, one can place the center at infinity and obtain pure translation. Conversely, one can obtain tipping around centroid by employing large tipping moment or a pure couple.

Atta (1964), performed an animal experiment on five rhesus monkeys whose ages were three to four years old.



His study dealt with a clinical and histologic examination of force magnitudes and determination of the center of rotation. This was accomplished by applying a single force to move the maxillary central incisors lingually. Coil springs measured and activated were tied between a lingual arch and the central incisors. These springs were used to deliver light force values of 10 gms.-75 gms. and heavy force values of 100-300 gms. With the use of radiographic and histologic cross-sections, Atta concluded that the teeth moved by light force value had a higher rate of movement than those with heavier force values. In addition, he found that the light and heavy forces tipped the tooth around the same center of rotation. The results of his investigation indicated that the center of rotation, during tooth movement, is determined by force to moment ratio, not the single value of each.

Kostiwa and Jeffry (1965), using four rhesus monkeys whose teeth have been subjected to light differential forces, found that their force system intruded the second premolar and reciprocally extruded the first premolar and molar tooth. Their appliance consisted of two horizontal helical loop springs with one and one half turns in each helix. They developed a method which would precisely measure the physical changes in tooth position in relation to two

reference points which aided in correlation with histologic changes. These changes in tooth position were measured occluso-gingivally and bucco-lingually. With the use of an instrument to accept transfer units, radiographs, and study casts they were able to evaluate their reciprocal vertical force system, in light of their histologic findings.

Geigel (1965), studied the biophysics of tooth movement by means of a three dimensional analog. Pure couples were applied to the model tooth by means of a rig that consisted of a flexible steel blade three inches wide and thirty-one inches long; a round steel rod fifteen inches long, and a large pulley mounted rigidly on the steel rod. A moment of force was transmitted through the flexible steel blade to the tooth where it was expressed as a couple because of the two point contact that the blade with two points (screws) on the labial surface of the model tooth. Seven different weights ranging from one half pound to four pounds were suspended from the pulley at separate intervals and readings of crown deflection and root deflections were taken. Geigel found that tipping occurred about a point which became stable when the moment of the couple was equal to or greater than 7.81 pound inches. Experimentally he showed that this definite point was the centroid of effective root area. He concludes by

stating:

Additional studies with physical models and animal research followed by further clinical investigations will be needed before all the concepts of biophysics of tooth movement are definitely established and universally understood.

CHAPTER IV

MATERIALS AND METHODS

1. Animal Selection:

The physical assessment of a tipping force system on the mandibular second premolars of two *Macaca Mulatta* rhesus monkeys (female) was the objective of this investigation. The rhesus monkey was chosen as the experimental animal because its dentition and tissue response are thought to be similar to those of man. This animal was also selected because of its wide usage in the experimental laboratory. The preliminary experimental design required that the teeth of the chosen monkey be caries free and comprise of full complement of permanent teeth excepting third molars. The age of a suitable animal could range from three years, eight months to five years, ten months (Hurme, 1960). The tooth and bone development are comparable to that of twelve to twenty year old orthodontic patients.

To insure having proper dentition, this investigator went to Shamrock Farms in Middletown, New York and selected his animals. One monkey weighed 11 lbs. 2 ounces; its age was estimated at five years, ten months. It was designated M-IA for purpose of identification. The second animal

weighed 9 lbs. 6 ounces, and its age was believed to be four years, six months. This animal was assigned an identification tag of M-IIIA.

2. Animal Housing and Care:

The experimental animals were housed in individual cages at the Animal Research Center of the Franklin Boulevard Community Hospital, Chicago, Illinois. This research facility is maintained under the auspices of the hospital's Department of Stomatology. The daily care of the animals was provided by a full-time diener of this research facility. Feeding and sanitation procedures were standardized. These animals were fed Rockland Laboratory Primate biscuits, water, and a vitamin injected orange. This diet was altered following the extraction of the mandibular first molars and the active period of experimentation with the appliances. The hard biscuits were softened with water to the consistency of a soft mash in the new diet to prevent damage to the orthodontic appliances, bananas were substituted for the orange.

3. Animal Handling:

There was a two week colonization period prior to the commencement of any experimental procedure to acquaint the animals to their surroundings. The operators wore surgical scrub suits, face masks, and rubber gloves at all

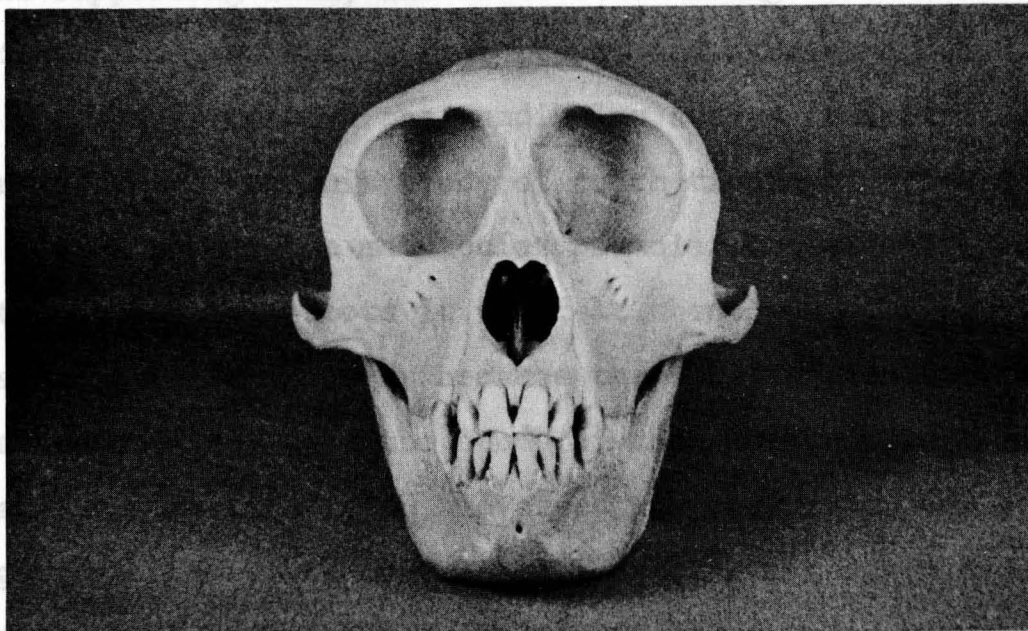
times to protect the animals as well as the operators from infections during direct contact.

A squeeze cage was used to transport and restrain the animals. This is a small portable cage with a sliding door on one end. After some training, the monkey learned to run into the squeeze cage when it was placed against the home cage. In this manner, the monkey is not handled manually, thus allowing for rapid handling and less trauma. The monkey was then transported to the animal surgery room, there the monkey was then restrained by compressing the movable wall of the squeeze cage. This forced the animal against the sliding door, which could be opened just enough for the operator to get hold of the leg, arm or head. General anesthetic was injected into a branch of the saphenous vein. For daily examination of the appliances, the head was held by one operator who wore heavy leather protective gloves while retracting the cheeks with tongue blades. Medication and force feedings were also done with the animals secured in this manner.

4. Selection of the Teeth for Movement:

The dentition of an adult rhesus monkey's skull (Figure 1), was studied to determine the selection of teeth for movement. After a careful study of the morphology of the crowns of the teeth, their occlusion, and the alveolar

A



B

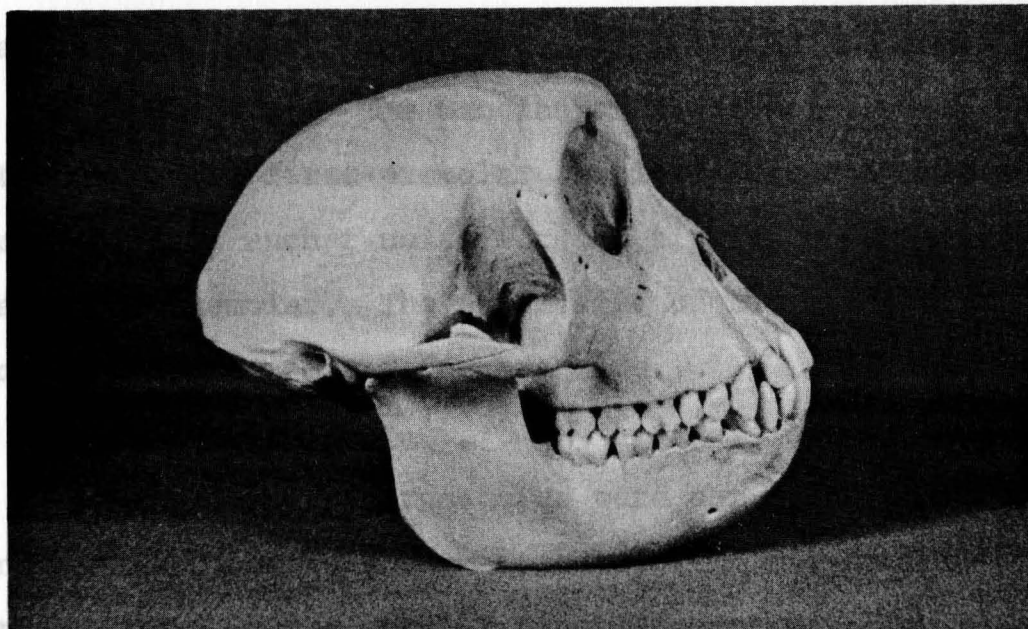


Figure 1

Frontal view (A) and lateral view (B)
of a dry skull of a rhesus monkey

bone supporting them, and after determining the root morphology from periapical radiographs and extracted teeth of the rhesus monkey, the mandibular second premolar teeth were selected for this study of tooth tipping. By virtue of the fact that the mandibular premolar teeth have two rather than three roots it was felt these would be more desirable teeth to study because they are very much like the teeth of man. In the study of the skull, it was seen that the posterior teeth had steep incline planes and a high degree of buccal overjet. These factors would provide a functional interference during tooth movement.

It was concluded from the aforementioned observations that the mandibular second premolar would be the tooth to be tipped distally. The mandibular first molar would be extracted. The first premolar, canine and second molar would serve as anchor units for the tipping movement of the second premolar. The other side of the mandibular arch would serve as a reference side.

5. General Anesthesia:

The experimental procedures were performed under general anesthesia. Sodium Nembutal (2%) was administered intravenously at the rate of 50 milligrams per five pounds of body weight. Preceding the administration of the anesthetic, the animal was weighed in the squeeze cage

to determine the proper dosage.

After the dosage was determined and recorded, the monkey was forced against the sliding door of the squeeze cage and a lower leg was grasped. The limb was shaved, scrubbed with soap and water, and cleansed with alcohol in preparation for the intravenous injection. A tourniquet was applied and the drug was slowly administered.

The anesthetized animal was then transferred from the squeeze cage to the operating table. A suture was placed through the tip of the tongue so that it could be pulled away from the oral pharynx whenever the airway became obstructed. An opthalmic ointment of Butyn Sulfate and Metaphen was placed into each eye to prevent drying and post-operative infection. Two inch strips of surgical gauze were used to secure each leg to the operating table and the anesthetized animal was carefully examined to make certain than heart and respiration were normal before beginning with the experimental procedures. This was followed for all the experimental procedures.

6. Preparation of the Experimental Animal:

After general anesthesia had taken effect the research animal was prepared for the remaining experimental procedures. These were as follows:

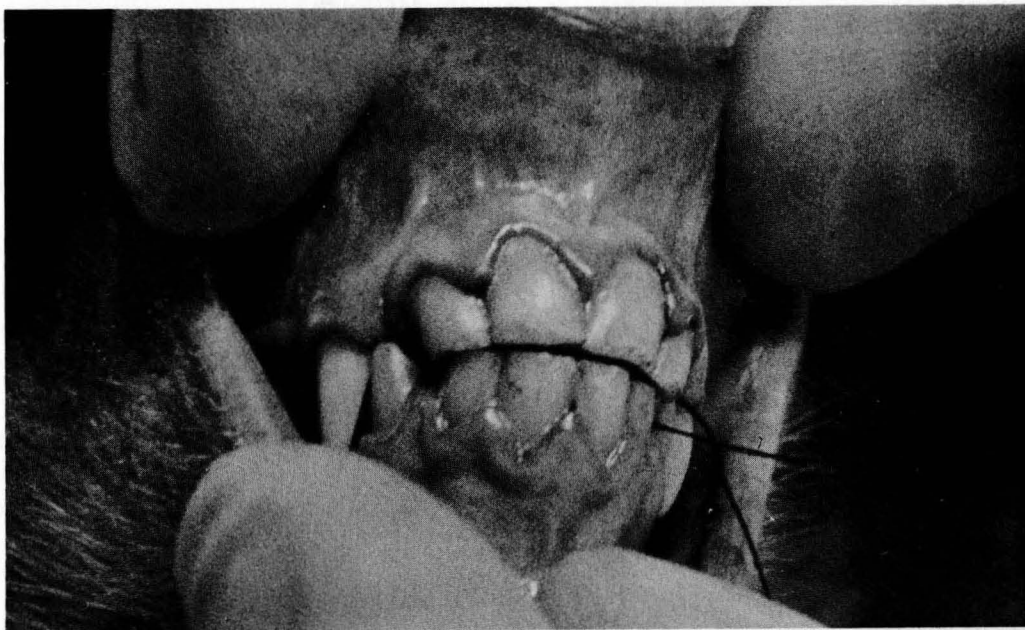
- (a) A prophylaxis was performed on each animal

to remove calcarious deposits on the teeth. The mucinous deposits and stains were removed from the teeth with a soft rubber cup. Intra-oral Kodacolor photographs were then taken of the animal's dentition (Figure 2).

(b) Full mouth impressions of the mandibular and maxillary teeth were taken in order to obtain study and working models of the teeth. Prior to the preparation of the experimental animal, acrylic impression trays were prepared on the dental arches of a rhesus monkey dry skull. These acrylic impression trays were tried for size in the mouth of the experimental animal. They were then coated on their inner surface with rubber adhesive to grip the impression material about to be placed into them. After the adhesive had dried, Coe Heavy Rubber Base impression material was mixed and placed into the mandibular and maxillary trays. These were then placed on the teeth to obtain impressions. Working models of the dental arches were made from these impressions by vibrating Vel-Mix Class II stone into them. Appliances were fabricated on the working models.

(c) Small occlusal cavities were cut on the mandibular teeth for the placement of small silver amalgams for land mark identification. The silver amalgams served as reference points as shown in Figure 3, which could also

A



B



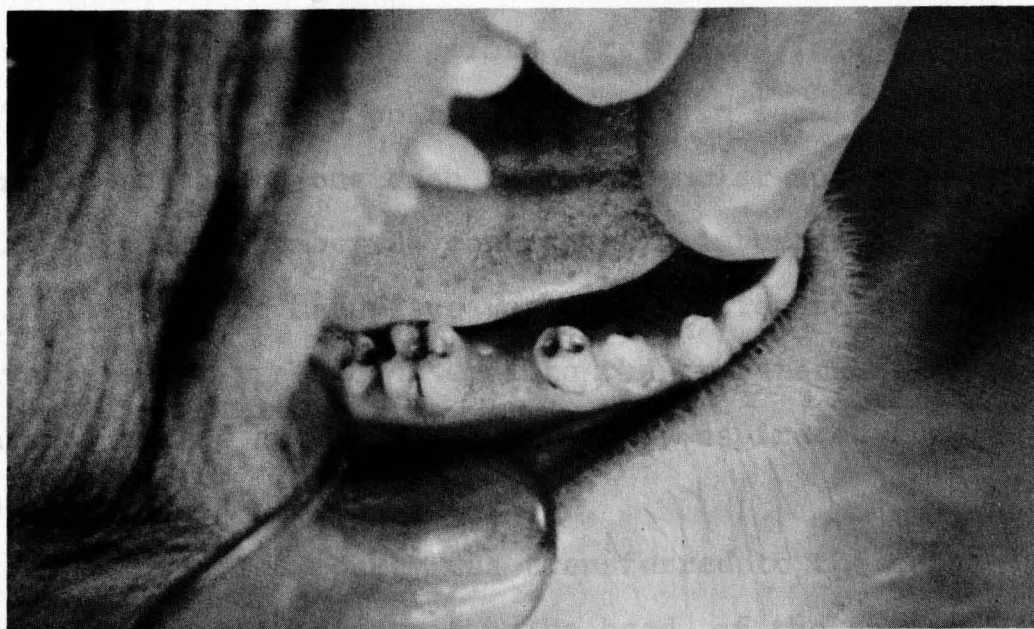
Figure 2

Intraoral photographs of the frontal
view (A) and lateral view (B)

be seen on examining the teeth and in the radiographs. 45

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(e) The mandibular first molar teeth were then
extracted. Surgical elevator and premolar forceps were
used to minimize amounts of

Figure 3

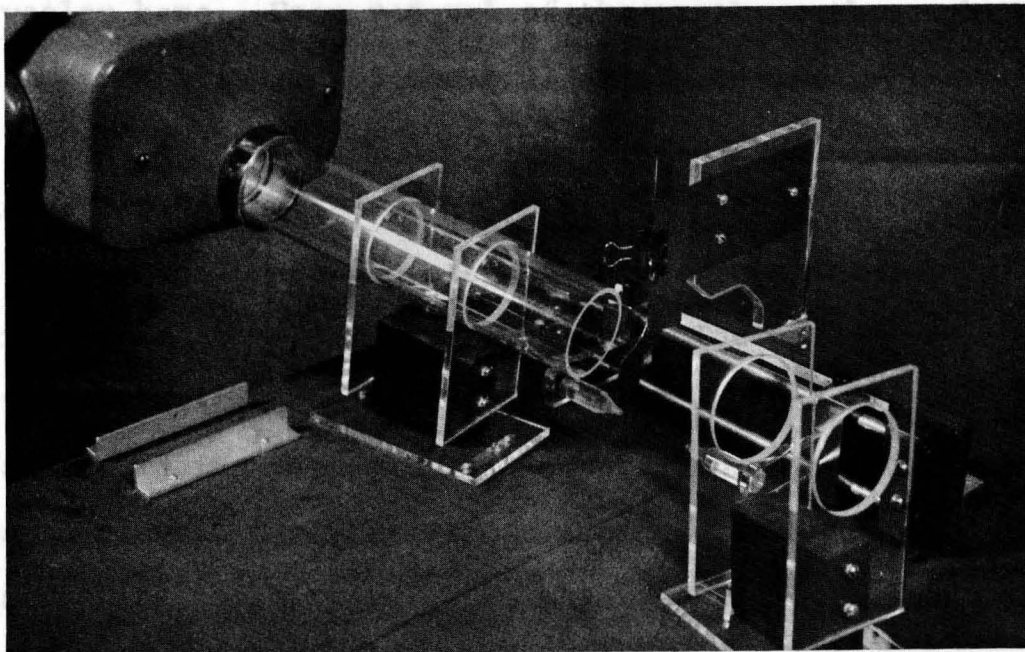
Animal prepared for experiment
right side (A) and left side (B)

be seen on examining the teeth and in the radiographs. These amalgams reference points were placed into the following teeth: two points were made in each second premolar tooth and one each in the premolar and second molar teeth. A number 34 contra-angle inverted cone bur in an air turbine handpiece was used to prepare the teeth. Silver amalgam was condensed into the preparation. Remnants of excess amalgam were carefully aspirated from the oral cavity of the monkey.

(d) The monkey was transferred to the cephalostat as shown in Figure 4. The head of the animal was placed between the ear posts while the monkey was in the supine position. A recording was made of the position of the ear posts on the millimeter scale for subsequent animal replacements. Bilateral periapical radiographs and occlusal roentgenograms were taken using the approximate film holders and placing the long cone of the x-ray machine into the required orienting device. The exposure time for each film was $1\frac{1}{2}$ seconds at 125 kilovolts and 25 milliamperes. The target to film distance was 16 inches. Kodak Ultra Speed film was used in this experiment.

(e) The mandibular first molar teeth were then extracted. Surgical elevators and premolar forceps were used to minimize the destruction of excessive amounts of

A



B

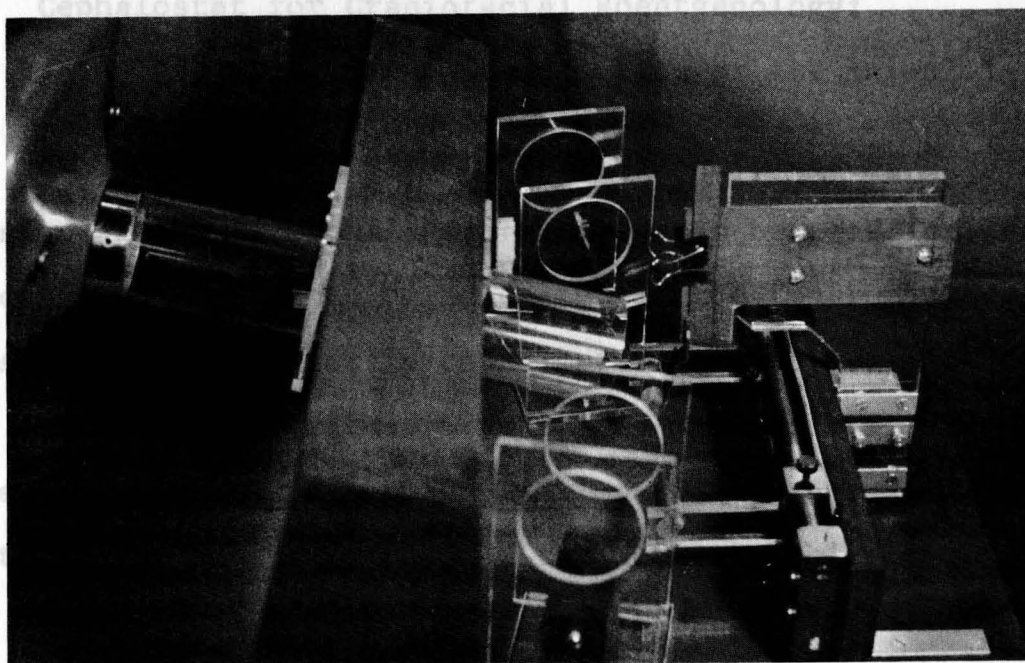


Figure 4

Animal headholder and x-ray orienting device for lateral radiographs (A) and occlusal radiographs (B)

alveolar bone. Upon removal of the teeth, a thorough inspection was made of the oral cavity to insure that no debris remained and that the hemorrhaging from the extraction had ceased.

The preceding steps completed the initial preparation of the experimental animal. The monkey was now returned to its cage and laid to rest on its side with his head facing downward. This positioning of the animal was to prevent oral secretions from accumulating and obstructing the airway. When the respiration was uniform, the tongue suture was removed.

7. Cephalostat for Craniofacial Roentgenology:

(a) Design and Construction of the Animal Cephalostat:

The dry skull of a rhesus monkey was used to design an animal cephalostat which could be used for serial roentgraphic pictures. The design of the instrument was based on the orthodontic cephalostat principle. The head of the animal was fitted between two movable ear rods while the animal was in a supine position (Figure 5). A millimeter scale measuring zero at the center enabled the operator to record the ear post positions for each animal so that they could be duplicated. A third reference point consisted of a knife edge incisal guide plate which was engaged

between the incisal edges of the mandibular incisor teeth. The mandibular occlusal plane was oriented perpendicular 49 to the base of the apparatus.

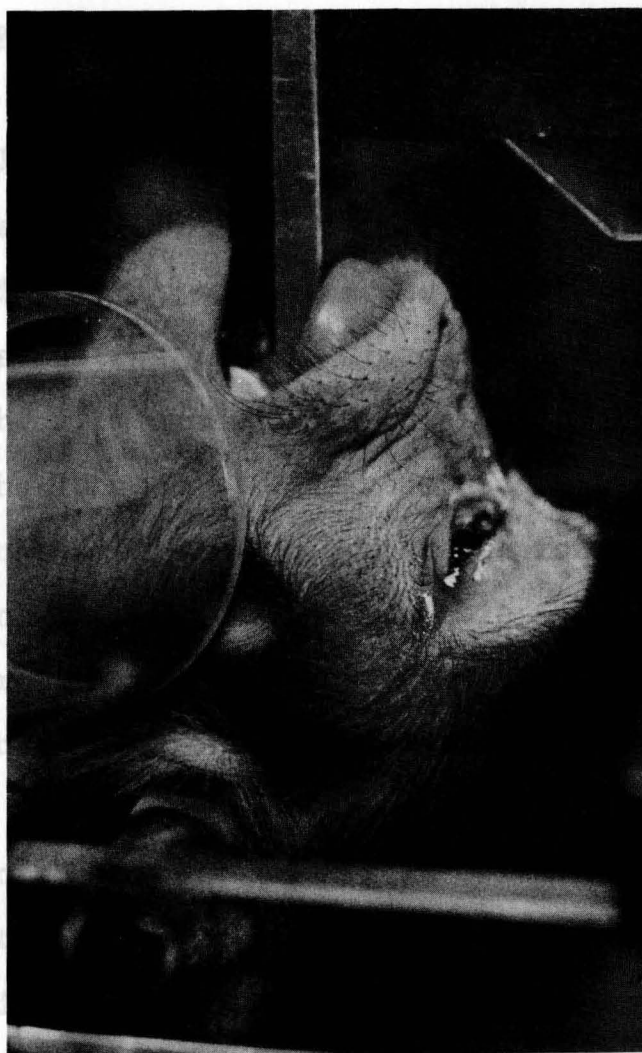


Figure 5

Anesthetized animal positioned in stereotaxic instrument

In addition to the periapical film holders, an occlusal film holder was designed. This holder was used with standard dental film measuring $1\frac{1}{2}$ " by $1\frac{3}{4}$ ". The film was attached to the holder with orthodontic elastics.

between the incisal edges of the mandibular incisor teeth. The mandibular occlusal plane was oriented perpendicular to the base of the apparatus.

Right and left intra-oral periapical film holders for parallel placement of the film were designed and added to the cephalostat instrument. The film holders are for pedodontic dental film measuring $7/8$ " by $1\ 3/8$ ". Orthodontic elastics were used to secure the films to the holders. The central ray was directed in a path perpendicular to the film packet, and this was achieved by angulating the long cone 10 degrees upward toward the mandibular occlusal plane to compensate for the inferior convergence of the body of the mandible and six degrees toward the frontal plane to compensate for the narrowing of the mandible anteriorly. The centroid of the mandibular second premolar tooth was estimated and the central ray was directed to that point. An orienting device was constructed to accommodate the long cone of the x-ray machine. This device was used to position the x-ray machine cone.

In addition to the periapical film holders, an occlusal film holder was designed. This holder was used with standard dental film measuring $1\frac{1}{2}$ " by $1\ 3/4$ ". The film was attached to the holder with orthodontic elastics.

The head of the animal was tipped back so that the mandibular occlusal plane was 15 degrees from the original vertical plane. The central ray was directed perpendicular to the film packet and centered on a point which represented the intersection in the mid-sagittal plane of the crown and a line between the two mandibular second premolar teeth.

(b) Testing the Reliability of Measurements from the Occlusal Roentgenograms:

The method of testing was to use the dry skull of a rhesus monkey which had small amalgam restorations selectively placed in the occlusal surfaces of some of the mandibular teeth, to take occlusal roentgenograms showing the restorations, and to make comparable measurements on both the roentgenographic pictures and the amalgams in the mandibular teeth.

In preparation two occlusal Class I restorations were placed in each mandibular second premolar; one was placed in each first premolar; and one was placed in each second molar. The skull was placed in the cephalostat so the mandibular occlusal plane was tipped 15° from a vertical plane toward the upper end of the cephalostat. The film pack for occlusal roentgenograms was inserted; the central ray of the x-ray machine head was directed perpen-

dicular to the plane of the film; and an occlusal radiograph was taken and processed.

The complete roentgenogram was transilluminated and a small pinhole was made directly through the film at the center of each image representing an amalgam restoration. Using a vernier caliper and magnifying glass, twenty-eight different measurements were made on the roentgenogram and also on the dry skull. The two sets of measurements were compared using Fisher's method of paired differences and student's t-test. There was no significant difference between the two sets of measurements so the roentgenographic method was accepted as being reliable for occlusal measurements.

8. Force System Design and Force Magnitude Determination:

The primary objective of this work was to design and study the application of a pure couple to tip the mandibular second premolar distally. The tooth was to be tipped into the extraction site of the mandibular first molar by means of an intrinsic force system. This force is one which is derived from a stressed wire affixed to the bracket of the mandibular second premolar. The canine, first premolar, and second molar were selected as anchor teeth.

It was necessary to determine a force value which would be compatible for optimal tooth movement. The force

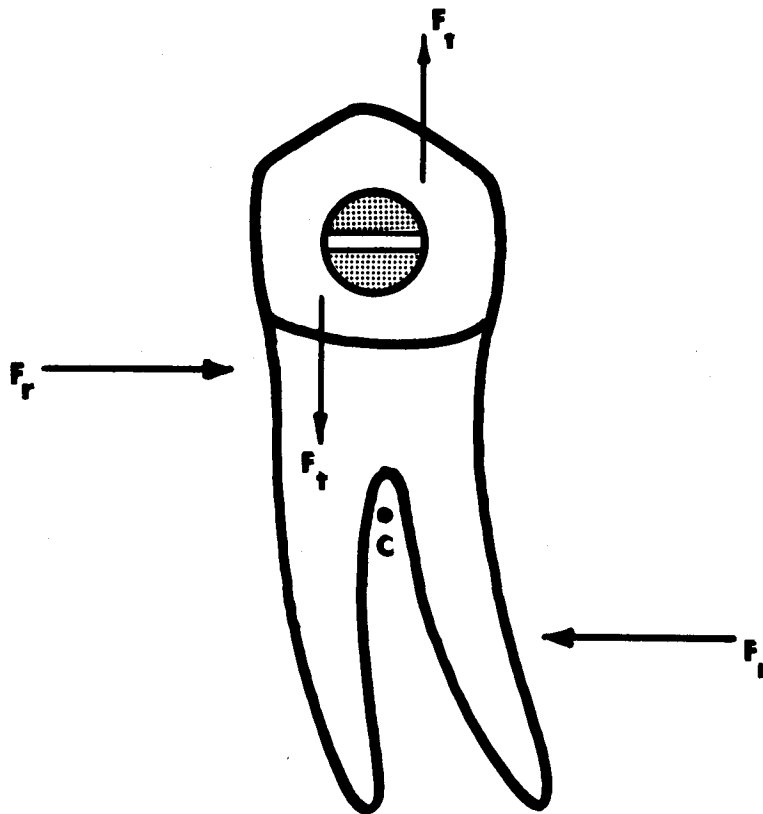
magnitude that will cause optimal tipping movement of a rhesus mandibular second premolar tooth is unknown.

Jeffry and Kostiwa (1965), in a preceding study, based their determination of force magnitude on a proportional relationship of the estimated root surface of a human tooth and a monkey tooth. With the aid of x-ray findings of teeth moved orthodontically without apparent root damage and the average tooth size values from Black's Tooth Size table, the average length of a premolar was determined. The dimensions of the monkey teeth were determined from periapical roentgenograms with the empirical values for the optimal movement of the human premolar of 180 to 200 grams having been suggested, a ratio between a human and monkey second premolar was established. They concluded that approximately 60% of the force magnitude suggested for the movement of the human premolar could be applied to a monkey premolar tooth. A force of 75 grams was selected to move orthodontically the mandibular second premolar in this experiment.

9. Analysis of the Force System:

The force system used in this experiment can best be analyzed with the aid of a free body diagram. This will demonstrate the effect of the force system on the tooth. Figure 6, is a schematic representation of the lingual

FREE BODY DIAGRAM
OF
MANDIBULAR SECOND PREMOLAR



F_t = Forces of Couple

F_r = Resisting Force

C = Centroid

FIGURE 6

views of the mandibular second premolar.

The appliance which will be described in the section on "Appliance Design" will nearly develop a pure couple when it is inserted into the bracket. The couple is represented by F_t-F_t on the free body diagram. With the application of the couple to the tooth, there will be an immediate response from the tissues in the form of a resisting couple or counter couple. The reacting force will develop in the periodontal ligament and alveolar process around the tooth. The counter couple is labelled F_r-F_r , and is a summation of the forces above and below centroid. These forces form resultants designated by the single arrows. This resisting couple is balanced around the true centroid of the root area. This explanation is based on the second and third laws of Equilibrium. The second law of equilibrium states: When a body is in equilibrium, the sum of all the forces in a horizontal direction is zero, $\sum F_h=0$. The third law of equilibrium states: When a body is in equilibrium the sum of all moments about a point is zero, $\sum M_p=0$.

The first law of equilibrium must also be considered. The first law of equilibrium states: When a body is in equilibrium, the sum of all the forces in a vertical direction is zero, $\sum F_v=0$. With the application of the

couple to the tooth, there are vertical shear forces present at centroid in the periodontal ligament on each side of the tooth. Due to the fact the body is in equilibrium, it may be assumed that resisting shear forces are present to counter the moment produced by the applied couple.

10. Appliance Design:

An orthodontic appliance can be designed and constructed to deliver a moment of force to the crown of a tooth, but it will inevitably exert some horizontal, vertical or transverse force on the tooth. Hence, it is not a pure couple. Moreover, as the activated appliance exerts forces against the bracket on the tooth, friction develops between the contacting surfaces of the wire and bracket, resulting in frictional forces acting on the tooth. There are also external forces such as those of occlusion which influence the application of orthodontic force systems. Therefore, in this experimental design of an orthodontic appliance that would produce a pure couple on the mandibular second premolar, it was essential that all of the adverse intrinsic and extrinsic forces be eliminated or greatly minimized.

The appliance used in this force system consisted of a spiral torsion spring, fabricated by winding flat

metal ribbon on itself in the form of a spiral. Two such springs joined at the center were wound concentrically. This design was selected because, through its stressed coils, two balanced moments of force could be transmitted to the tooth where they were expressed as a couple. This is due to the two point contact that the center section of the spring made with the bracket. The magnitude of the couple being applied to the tooth at any particular time would be exactly the same as the magnitude of the two moments.

A force magnitude of seventy-five grams was calculated for the movement of the mandibular second premolar teeth of the rhesus monkey, using empirical data from the studies of human and monkey teeth of Jeffry and Kostiwa (1965). In the studies of Jarabak and Fizzell (1963), centroid of a tooth is at a point 60% of the root length superiorly from the root apex. Using periapical x-rays of the rhesus monkey's posterior teeth, it was estimated that the distance from the centroid of the mandibular second premolar tooth to the center of the bracket was six millimeters. Therefore, the moment of force could be calculated with the predetermined force magnitude and the known length of the moment arm.

- (a) Average grams to orthodontically tip a tooth =
75.0 grams or 0.165 lbs.

- (b) Length of the moment arm = 6 millimeters
or 0.24 inches.

The moment of force was found to be 0.0398 lb. inches.

$$= .165 \text{ lbs} \times 0.24 \text{ inches}$$

$$= 0.0398 \text{ lb. inches}$$

The flat torsion spiral spring was designed as shown in Figure 7. The terminal extensions of the springs were made equal in length, to balance the extrusive components in one half of the spring against the intrusive components developed in the other half of the spring. In essence, two springs were incorporated into one spring with the main effect that the moments of force be applied as a couple at the center of the bracket. The calculated moment of force, which is 0.0398 lb. inches be divided by two (2) to obtain the torque of one spiral spring.

$$0.0398 \div 2 = 0.0199 \text{ lb. inches or about .02 lb. inches}$$

The spring design was determined with the following formulas:

$$n = \frac{SL}{(11) Eh} \quad P = \frac{Sbh^2}{6R} \quad S = \frac{6M}{bh^2}$$

In which:

b = width of the active material in inches

h = thickness of material in inches

E = Modulus of Elasticity (29×10^6 - manufacturer's specification)

L = length of active material in spring

M = torque in lb. inches

P = load in lbs.

R = lever arm: mean radius

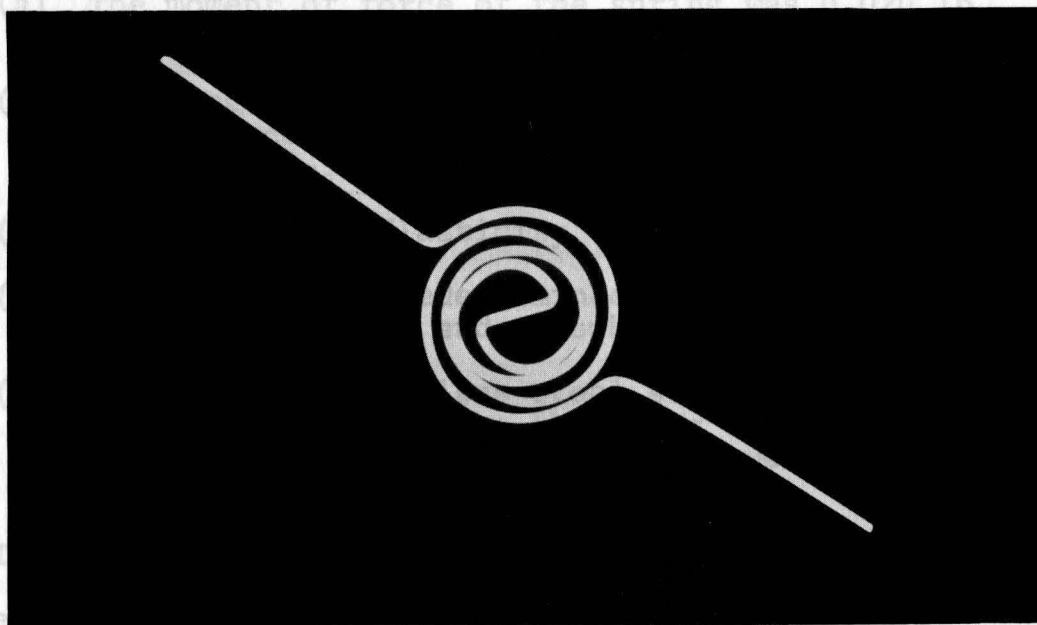
S = stress in p.s.i.

n = number of turns spring will give

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In the determination of the specifications of each spring, there were certain known or assumed factors. These were then applied in the formula and used to calculate the unknown factors. The known factors were as follows:

FLAT TORSION SPIRAL SPRING



the following specifications:

SPRING SPECIFICATIONS

1. Length of active material in spring 1.52"
2. Diameter of the spring (5 mm.)2"
3. The spring will make two convolutions when stressed by a 45° deflection.
4. Torque 0.020 lb. in.
5. Width of the material 0.060"

FIGURE 7

S = stress in p.s.i.

n = number of turns spring will give

In the determination of the specifications of each spring, there were certain known or assumed factors. These were then applied in the formula and used to calculate the unknown factors. The known factors were as follows:

- (a) The moment of force of the spring was 0.020 lb. inches.
- (b) The length of the active material was .76 inches for 1.87 convolutions. (See appendix for derivation.)
- (c) The Modulus of Elasticity was 29×10^6 p.s.i.
- (d) The spring was predetermined to have a total deflection of 45° and a working range of 20° .
- (e) Width of the stainless steel stock material was 0.060 inches. The thickness of the spring and the fiber stress of the steel were checked as shown in the Appendix I.

The spring was manufactured from stainless steel stock by the American Spring and Wire Speciality Company with the following specifications:

SPRING SPECIFICATIONS

- 1. Length of active material in spring 1.52"
- 2. Diameter of the spring (5 mm.)2"
- 3. The spring will make two convolutions when stressed by a 45° deflection.
- 4. Torque 0.020 lb. in.
- 5. Width of the material 0.060"

6. Thickness of the material	0.006"
7. Maximum Fiber Stress	90,000
8. Modulus of Elasticity	29×10^6 p.s.i.
9. Number of turns spring will give125
10. Working range of the spring	20°

11. Appliance Construction:

The appliances for this experiment were constructed on the full maxillary and mandibular models. These models were prepared from rubber base impressions which were poured in Vel-Mix Dental plaster. The mandibular teeth on the stone models that were intended for banding, were relieved at the gingival margin, to facilitate band adaptation. The first mandibular molars were cut off of the stone models, because these teeth were extracted after the impressions were taken. The bands for the mandibular canines, and premolars were made from 0.004 inch stainless steel banding material and the molar bands from 0.006 inch banding material.

In order to establish a reference base which would be stable, the mandibular canines, first premolars, and second molars were selected as reference teeth. A 0.036 inch passive mandibular buccal arch was formed for each appliance and made to contact all of the teeth and bands

except the second molars. The arch was then soldered to all of the bands except the second premolar bands. The arch was placed on the buccal surfaces of the teeth to prevent interference with the active appliance. Clinical experience in the care and handling of the animals dictated that the appliance be placed in an area inaccessible to the monkey's reach, hence it was placed on the lingual surface.

The flat coil spring center or horizontal section was placed into a round slotted bracket, designed in the manner of a Tinker Toy peg as illustrated in Figure 8. The diameter of the bracket was .030 inches, the horizontal slot was 0.010 inches wide, and 0.060 inches in depth. The bracket was first aligned with the horizontal slot perpendicular to the long axis of the tooth and then soldered to the second premolar band. No other brackets were placed on the active side or the reference side. The spring was ligated to two eyelets which were soldered on to the mesial aspects of the first premolar and second molar. A stainless steel ligature wire, .010" in diameter, was loosely ligated around the terminal portions of the spring to allow them to slide freely through the eyelet.

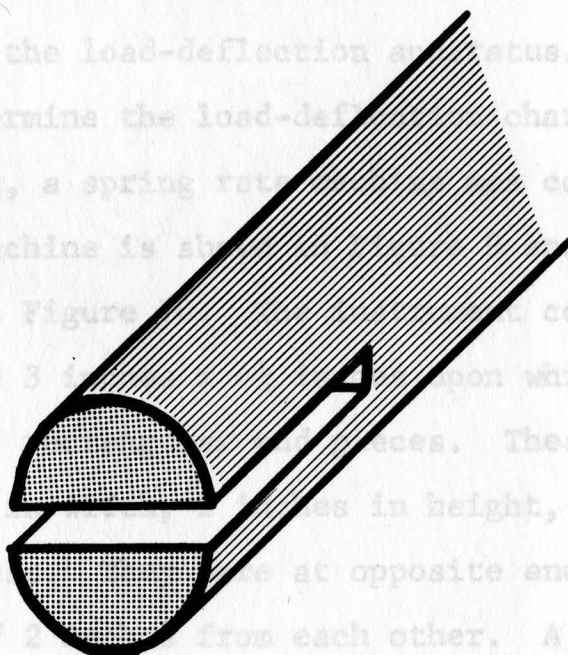
In the passive state, the spring had its terminal ends

deflected in a 45° angle from the center horizontal section. The spring was activated by placing the horizontal section into the bracket after the ends had been ligated.

BRACKET FOR COIL SPRING

The requirements of the active element were that it develop a couple of .04 lb. inches when deflected 45° and have a linear characteristic. The flat spiral torsion springs were tested on a load-deflection testing apparatus. The final selection of the active elements was based on their performance in the load-deflection apparatus.

In order to determine the load-deflection characteristics of each spring, a spring rate testing machine was constructed. A top view of this machine is shown in Figure 8. A side elevation is shown in Figure 9. The machine consisted of a rectangular base 3 inches long and 1 1/2 inches wide. Mounted on two vertical end pieces were two vertical plates. These end pieces were 3 inches high, 1 1/2 inches in height, and 3/8 of an inch in thickness. They were mounted at opposite ends of the base at a distance of 2 inches from each other. A .025 inch in diameter hole was made 1/2 inch from the top of each end piece to accommodate a set of micro-ball bearings.



HORIZONTAL SLOT: .010" wide

.060" in depth

BRACKET

: .030" diameter

A round brass shaft extended through the two sets of ball bearings in the end pieces. One end of the shaft was fabricated to simulate the round bracket used in the animal

FIGURE 8

deflected in a 45° angle from the center horizontal section. The spring was activated by placing the horizontal section into the bracket after the terminal ends had been ligated.

The requirements of the active element were that it develop a couple of .04 lb. inches when deflected 45° and have a linear characteristic. The flat spiral torsion springs were tested on a load-deflection testing apparatus. The final selection of the active elements was based on their performance in the load-deflection apparatus.

In order to determine the load-deflection characteristics of each spring, a spring rate machine was constructed. A top view of this machine is shown in Figure 9 and a side elevation is shown in Figure 10. The instrument consisted of a rectangular base 3 inches x $4\frac{1}{2}$ inches upon which were mounted two vertical, rectangular end pieces. These end pieces were 3 inches in width, 2 inches in height, and $\frac{3}{8}$ of an inch in thickness. They were at opposite ends of the base at a distance of 2 inches from each other. A .025 inch in diameter hole was made $\frac{1}{2}$ inch from the top of each end piece to accommodate a set of micro-ball bearings.

A round brass shaft extended through the two sets of ball bearings in the end pieces. One end of the shaft was fabricated to simulate the round bracket used in the animal

SIDE VIEW OF
LOAD DEFLECTION INSTRUMENT

LOAD DEFLECTION INSTRUMENT

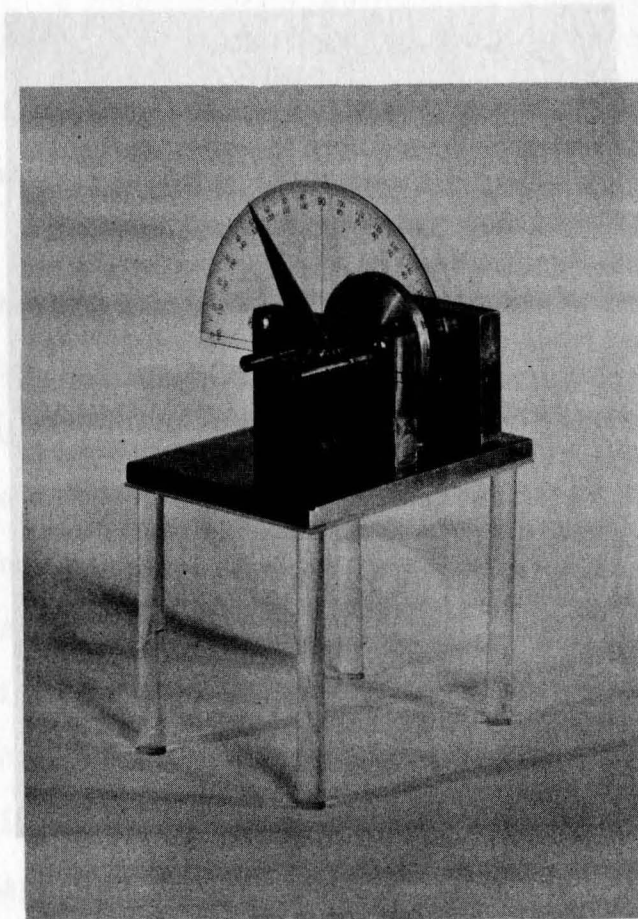


FIGURE 9

experiment. This part of the shaft was 0.030 inch in diameter and the horizontal slot was .010 inch wide x .060 inch deep. Attached to this end of the shaft was a pointer which was used to indicate the angular degrees of rotation of the shaft. These could be read from a protractor mounted on the vertical end piece, as again seen in Figure 10.

SIDE VIEW OF LOAD DEFLECTION INSTRUMENT

Two round brass rods were mounted on the vertical end piece near the slotted end of the shaft. They were spaced 12 millimeters on each side of the shaft and parallel with the shaft.

The spring was applied in the following manner. The ends of the spring were loosely ligated to the two rods. A 20 inch stainless steel ligature was attached to the horizontal portion of the spring was then placed in the upper slot of the shaft. With the spring placed in the slot, the pointer was made of the pointer position on the protractor. This was the initial or zero reading.

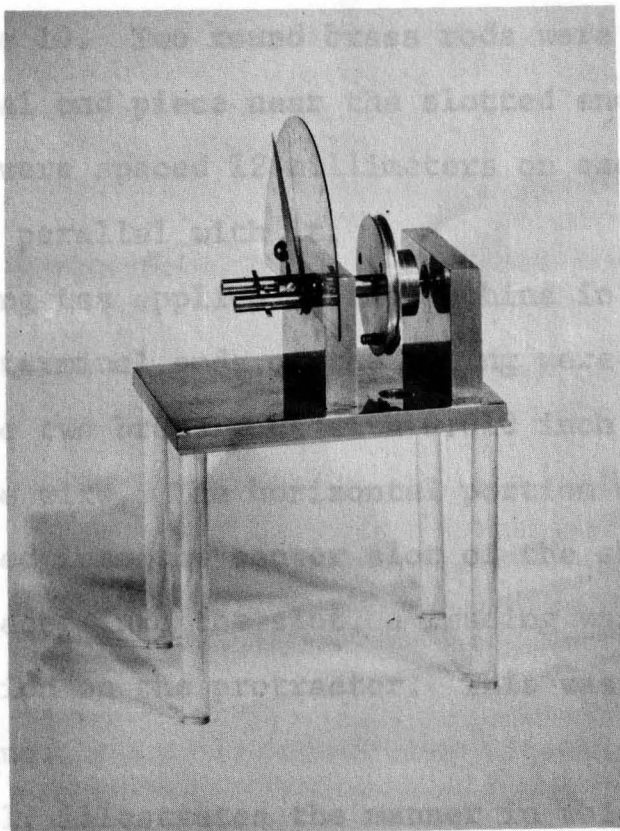


Figure 10 illustrates the manner in which a moment of force was applied to the shaft. A large pulley was mounted rigidly in the middle of the shaft. The length of the moment arm was 18.951 cm. which was the radius of the pulley.

FIGURE 10

A thread was wrapped around the pulley and secured

experiment. This part of the shaft was 0.030 inch in diameter and the horizontal slot was .010 inch wide x .060 inch deep. Attached to this end of the shaft was a pointer which was used to indicate the angular degrees of rotation of the shaft. These could be read from a protractor mounted on the vertical end piece, as again seen in Figure 10. Two round brass rods were mounted on the vertical end piece near the slotted end of the shaft. They were spaced 12 millimeters on each side of the shaft and parallel with it.

The spring was applied to the machine in the following manner. The terminal ends of the spring were loosely ligated to the two brass rods with 0.010 inch stainless steel ligature wire. The horizontal portion of the spring was then placed into the center slot of the shaft. With the spring placed into the slot, a reading was made of the pointer position on the protractor. This was the initial or zero reading.

Figure 11, illustrates the manner in which a moment of force was applied to the shaft. A large pulley was mounted rigidly in the middle of the shaft. The length of the moment arm was 18.961 mm. which was the radius of the pulley.

A thread was wrapped around the pulley and secured

to it. The other end of the thread passed through a hole in the base to a light tray for holding chemical balance weights as seen in Figure 12. The use of various weights provided a means of applying different moments to the shaft.

As the applied moment was increased, the deflection of the spring increased and the amount of this increase was indicated by the pointer on the protractor. This made it possible to plot torque versus deflection of the outer part of the spring.

Figure 13, illustrates the characteristic curve found in the springs used in the experiment. Figure 1, represents the moment of force applied to the spring of deflection between 0 and 45°.

12. The Maxillary Bite Plane:

In order to eliminate external factors, such as occlusion from interfering with the orthodontic movement of the teeth, a maxillary bite plane was constructed from an acrylic resin on the maxillary stone model. The bite plane, as shown in Figure 14, covered the anterior teeth from the canine to canine, and extended one to two millimeters above the gingival margins of the teeth. The bite plane was made parallel to the occlusal plane. It opened the bite in the anterior region approximately 2.5 millimeters.

FIGURE 11

DETERMINATION OF MOMENT OF FORCE

to it. The other end of the thread passed through a hole in the base to a light tray for holding chemical balance weights as seen in Figure 12. The use of various weights provided a means of applying different moments to the shaft.

As the applied moment was increased, the deflection of the spring increased and the amount of this increase was indicated by the pointer on the protractor. This made it possible to plot torque versus deflection of the center part of the spring.

Figure 13, illustrates the linear characteristic found in the springs used in the experiment. Table I, represents the moment of force applied at 5° intervals of deflection between 0 and 45° .

12. The Maxillary Bite Plane:

In order to eliminate external factors, such as occlusion from interfering with the orthodontic movement of the teeth, a maxillary bite plane was constructed from an acrylic resin on the maxillary stone model. The bite plane, as shown in Figure 14, covered the anterior teeth from the canine to canine, and extended one to two millimeters above the gingival margins of the teeth. The bite plane was made parallel to the occlusal plane. It opened the bite in the anterior region approximately 2.5 millimeters. The tips of the maxillary canine teeth which pro-

LOAD DEFLECTION CURVES

OF

FLAT COIL SPRINGS

LOAD DEFLECTION INSTRUMENT

WITH WEIGHTS

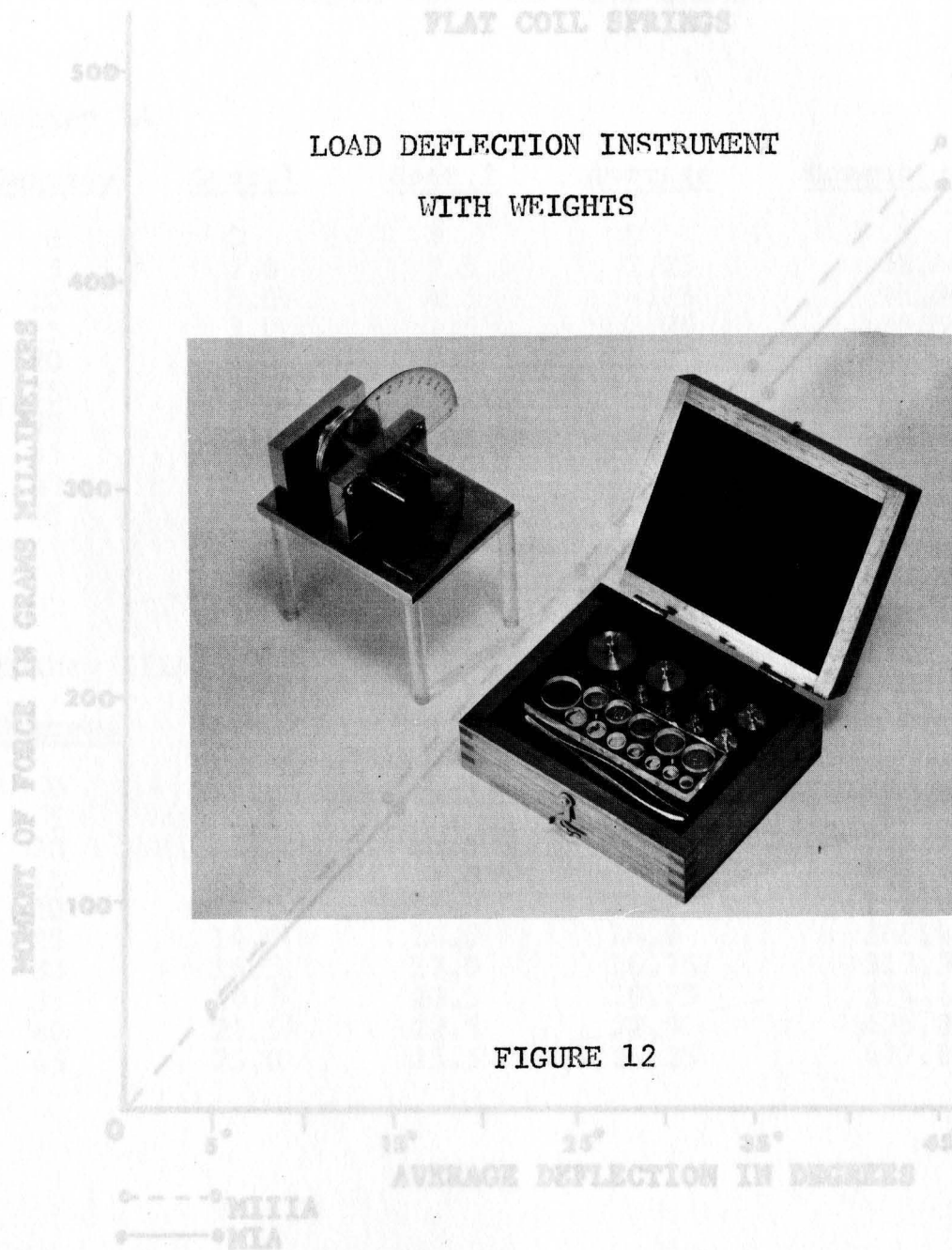


FIGURE 12

FIGURE 13

LOAD DEFLECTION CURVES

OF

FLAT COIL SPRINGS

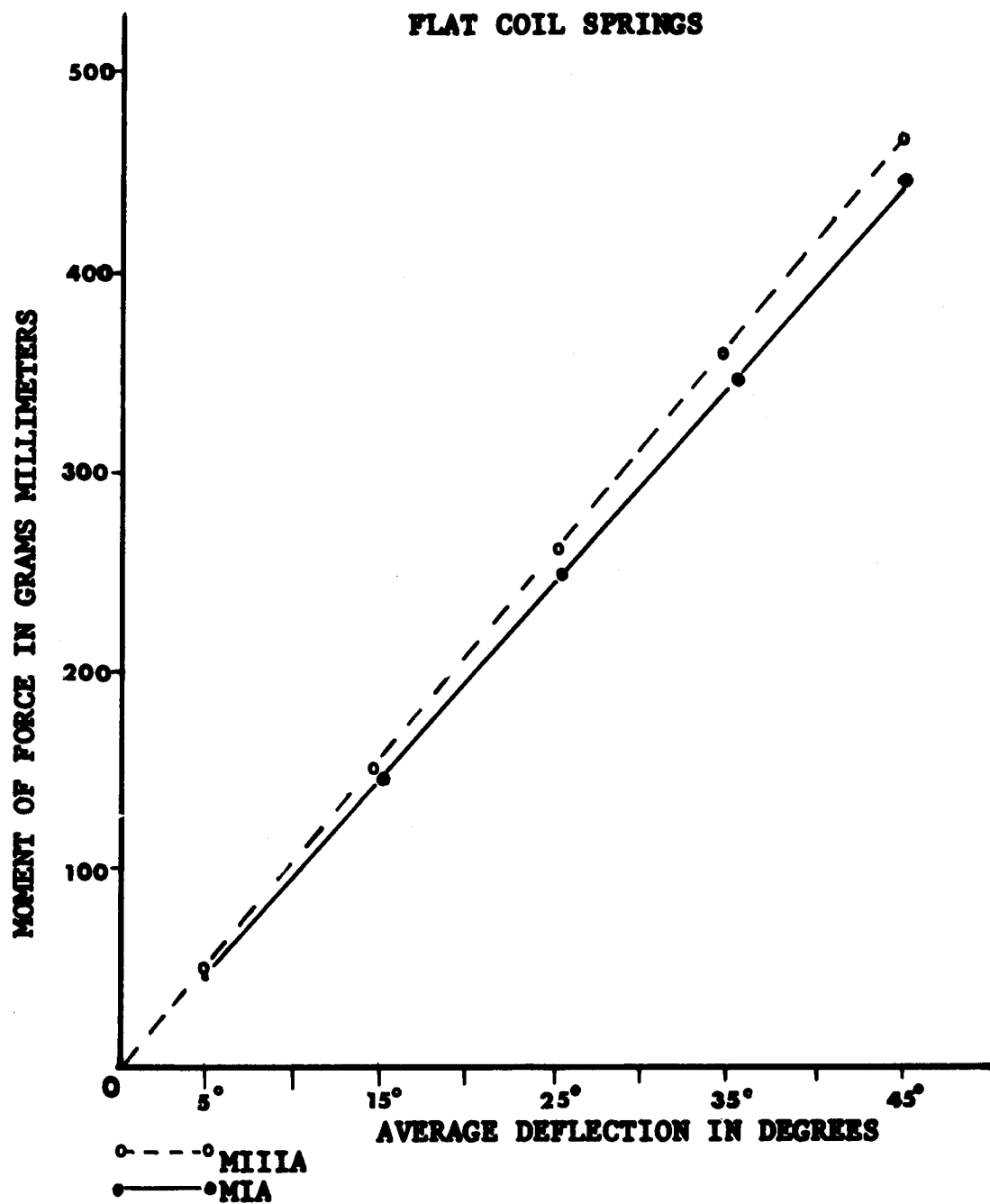


FIGURE 13

TABLE I
DATA SHEET FOR FLAT COIL SPRING

Monkey IA

<u>Degrees</u>	<u>Oper.1</u>	<u>Oper.2</u>	<u>Average</u>	<u>Moment (gm.mm)</u>
0	0	0	0	0
5	2.0	2.5	2.25	42.66
10	5.0	4.5	4.75	90.06
15	7.0	7.5	7.25	136.51
20	10.0	10.0	10.0	189.61
25	13.0	12.5	12.75	241.75
30	15.5	15.0	15.25	289.15
35	18.0	17.5	17.75	336.55
40	21.0	20.5	20.75	393.44
45	23.5	23.5	23.5	445.58

Monkey IIIA

<u>Degrees</u>	<u>Oper.1</u>	<u>Oper.2</u>	<u>Average</u>	<u>Moment (gm.mm)</u>
0	0	0	0	0
5	2.5	2.7	2.6	49.29
10	5.5	5.5	5.5	104.28
15	8.5	9.0	8.75	165.90
20	11.0	11.5	11.25	212.83
25	14.0	14.0	14.0	265.45
30	16.5	17.0	16.75	317.91
35	19.5	20.5	19.75	374.47
40	22.5	22.5	22.5	426.62
45	25.0	25.5	25.25	477.87

truded through the bite plane were reduced on the stone model and subsequently, in the mouth when the appliance was cemented. The corresponding mandibular canine cusps were also reduced to the level of the four mandibular incisor teeth to equalize the stress on the bite plane.

MAXILLARY ANTERIOR BITE PLANE

IN THE MOUTH

13. Appliance Cementation and Activations

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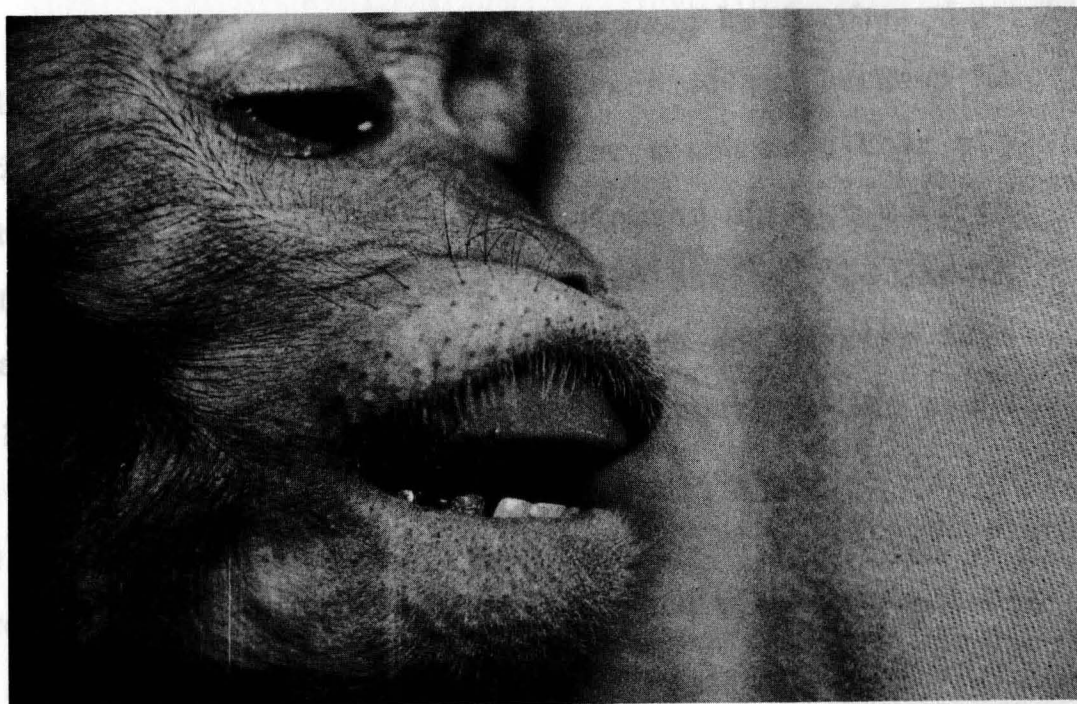


FIGURE 14.

canine cusps were reduced as previously described. The active element of the appliance was ligated into place with 0.010 inch ligature wire. After placing the animal into the cephalostat, radiographic records were taken. These consisted of one occlusal radiograph and right and left periapical radiographs.

The forearms of the animal were shaved and the skin

truded through the bite plane were reduced on the stone model and subsequently, in the mouth when the appliance was cemented. The corresponding mandibular canine cusps were also reduced to the level of the four mandibular incisor teeth to equalize the stress on the bite plane.

13. Appliance Cementation and Activation:

The animal was given a general anesthetic when the appliance was to be inserted. Contact points between the mandibular first and second premolar teeth on either side of the arch were relieved with a diamond disc to make the teeth accessible for placement of the bands. The mandibular appliance was placed on the teeth and checked for fit; necessary adjustments were then made. A bite plane for the maxillary anterior teeth was placed on those teeth and adjusted. Both the mandibular appliance and bite plane were cemented to their respective teeth with copper cement, as seen in Figure 15. Excess cement was removed and the canine cusps were reduced as previously described. The active element of the appliance was ligated into place with 0.010 inch ligature wire. After placing the animal into the cephalostat, radiographic records were taken. These consisted of one occlusal radiograph and right and left periapical radiographs.

The forearms of the animal were shaved and the skin

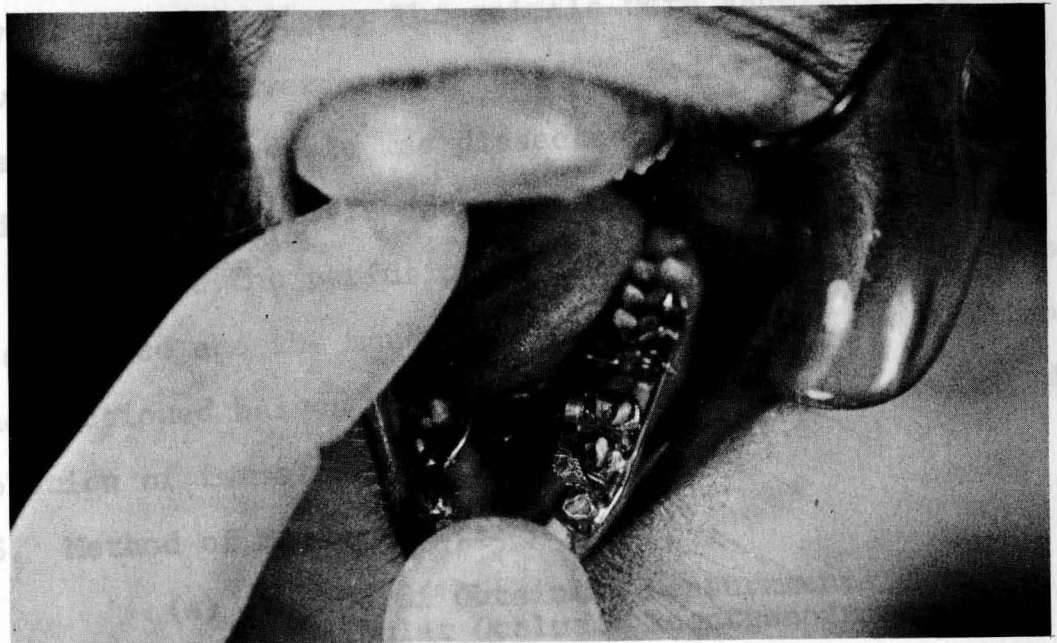
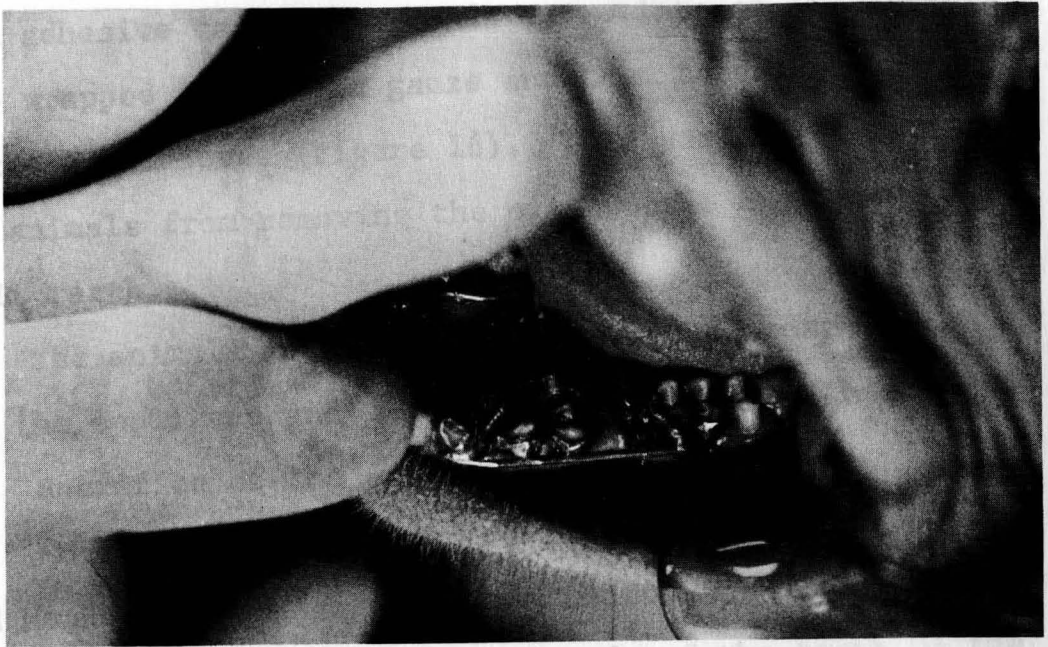


FIGURE 15

ANIMAL WITH EXPERIMENTAL APPLIANCE IN THE MOUTH

was painted with a tincture benzoin to minimize irritation from adhesive tape. The hands and wrists of the monkeys were wrapped loosely in gauze and then taped to form small mitten-like gloves (Figure 16). This was done to prevent the animals from removing the orthodontic appliances from their teeth.

The animals were placed in the squeeze cage daily and the appliance and the taped forearms were checked.

14. Sacrifice of the Animal:

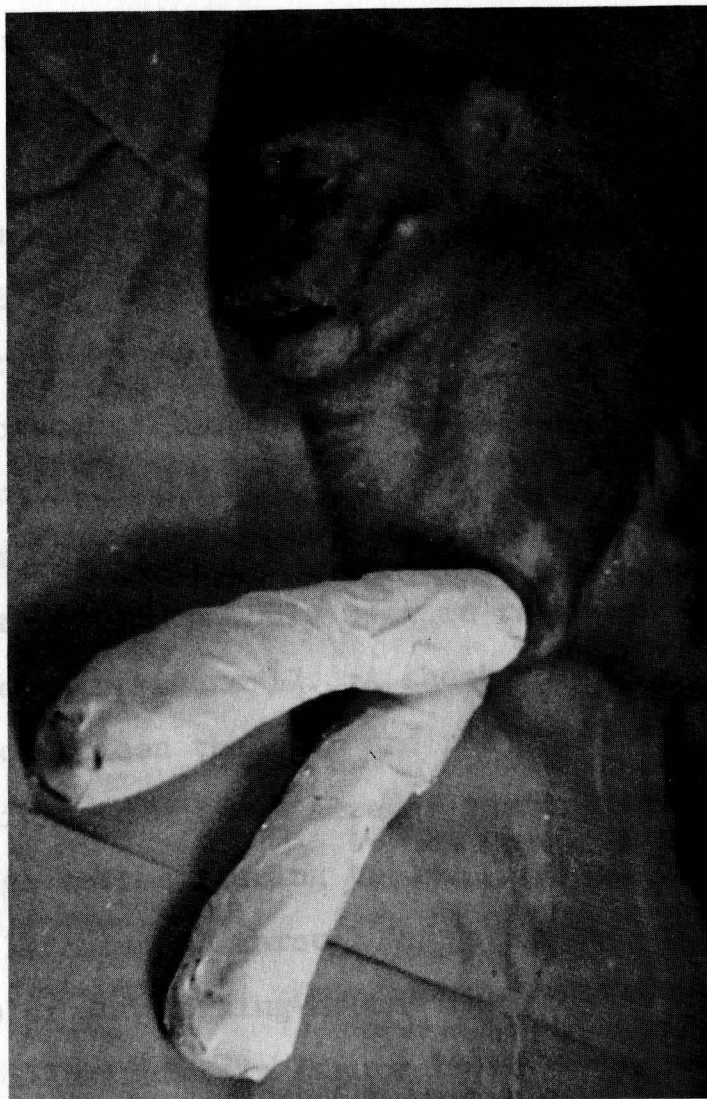
Monkey IIIA was sacrificed on the twenty-third day and Monkey IA was sacrificed on the twenty-eighth day. Final radiographic records were made of the teeth on the day of the sacrifice. The animals were sacrificed by giving them an overdose of the (2%) Sodium Nembutal anesthetic. The mandible was dissected from the head of the animal and the condyle and coronoid process were removed to facilitate the perfusion of the tissues. The appliance was removed and the mandible was sectioned at the midline. The sectioned halves were then placed into a 10% buffered solution of formalin.

15. Method of Measurements:

- (a) Method of Obtaining Measurements from the Mandibular Occlusal Roentgenograms:

The mandibular occlusal roentgenograms were taken

at pre-determined times during the experiment. These times were the first, fourth, eighth, sixteenth, and twenty-third day, the day of the experiment. These series of experiment were reference tions were of a 3-1/2 directly image. To trans-illu room. The probe of work as se was placed in mainta vent dama assigned second mo molar as



Orienting the pinhole perforations to reference area required the use of a grid system. This was provided by a coordinate paper laid off in major units of centimeters and minor units of millimeters. Graph paper by Kauffel

FIGURE 16

at pre-determined times during the experiment. These times were the first, fourth, eighth, sixteenth, and twenty-third day, the day of the sacrifice of the animal. These series of mandibular roentgenograms taken during the experiment were considered individually. For this study, the reference points which were images of the amalgam restorations were accurately spotted on each film with the aid of a 3-1/2" magnifying lens. A small pinhole was made directly through the film at the center of each amalgam image. To accomplish this spotting with precision, a trans-illuminated tracing table was used in a darkened room. The pinholes were made with a phonograph needle probe of the type commonly used in radio and electronic work as seen in Figure 17. A sheet of cellulose acetate was placed between the film and the tracing table to aid in maintaining a uniform size of perforation and to prevent damage to the tracing table. The perforations were assigned letters "A" through "H" starting with the left second molar and working around the arch to the opposite molar as illustrated in Figure 18.

Orienting the pinhole perforations to reference axes required the use of a grid system. This was provided by a coordinate paper laid off in major units of centimeters and minor units of millimeters. Graph paper by Keuffel

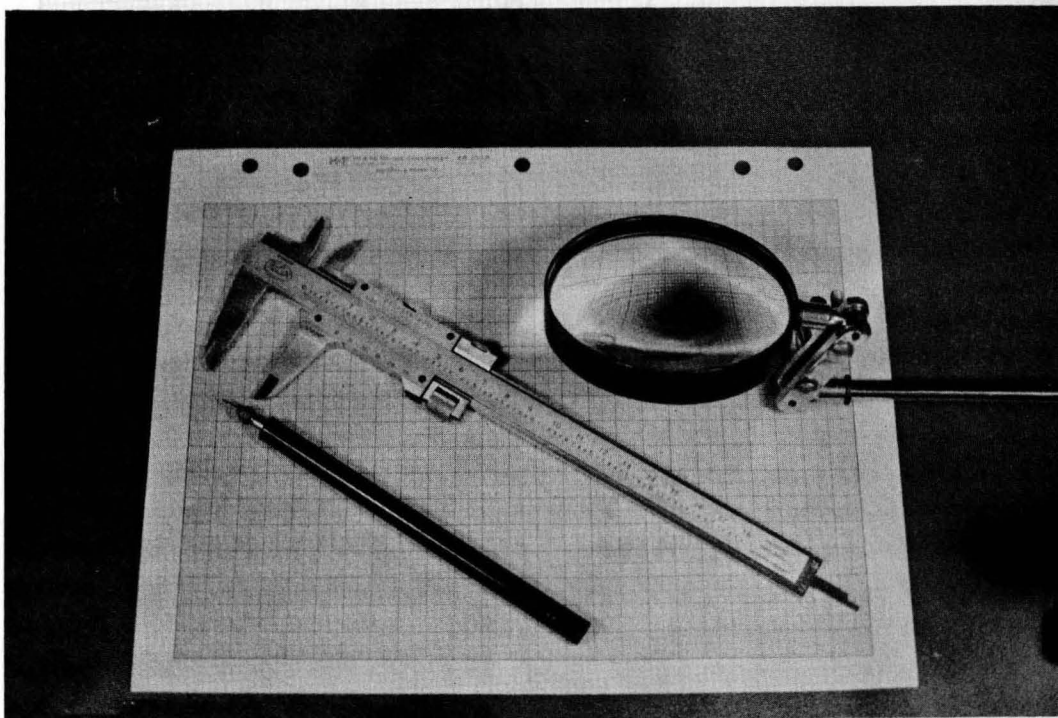


FIGURE 17

GRAPH PAPER, VERNIER CALIPER, PHONOGRAPH NEEDLE PROBE,
AND MAGNIFYING LENS

FIGURE 18

(A) GRAPH FOR OCCLUSAL X-RAY
(B) GRAPH FOR LATERAL X-RAY

and Esser Company fulfilled these requirements.

A rectangular coordinate system was used for making measurements of the mandibular occlusal roentgenograms. In order to create a rectangular coordinate system, two mutually perpendicular lines ($X'X$ and $Y'Y$) must be drawn at 0. These reference lines, called axes, divide the plane into four parts or quadrants. These quadrants are numbered I, II, III, and IV, starting with the upper right hand quadrant and reading in a counter-clockwise direction. The point of intersection of the axes is called the origin or 0. The line $X'X$ is called the axis of abscissas or X axis and is generally taken to be horizontal. The $Y'Y$ line is called the axis of ordinates, or Y axis, and is taken to be vertical. All distances measured horizontally to the right or vertically upward are considered positive, and all distances measured horizontally to the left or vertically downward are considered negative.

Each mandibular occlusal film, as shown in Figure 19, was again returned to the tracing table, this time with a sheet of graph paper between the sheet of cellulose acetate and the film. The graph paper was oriented so that point H was superimposed on the origin of the coordinate system. Point A was superimposed on the axis of ordinates or $Y'Y$ line so that the remaining points were located in quadrant I.

With these points correctly located on the graph paper.

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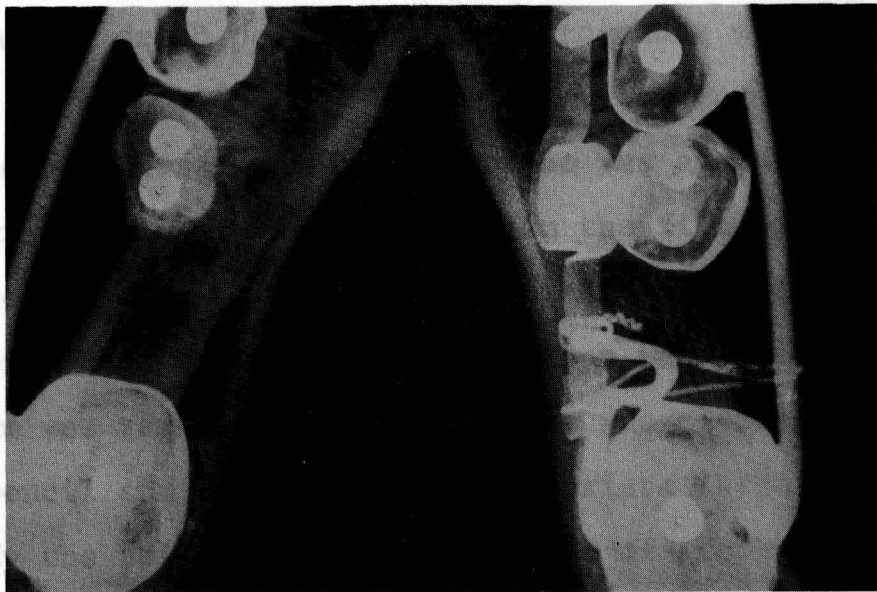
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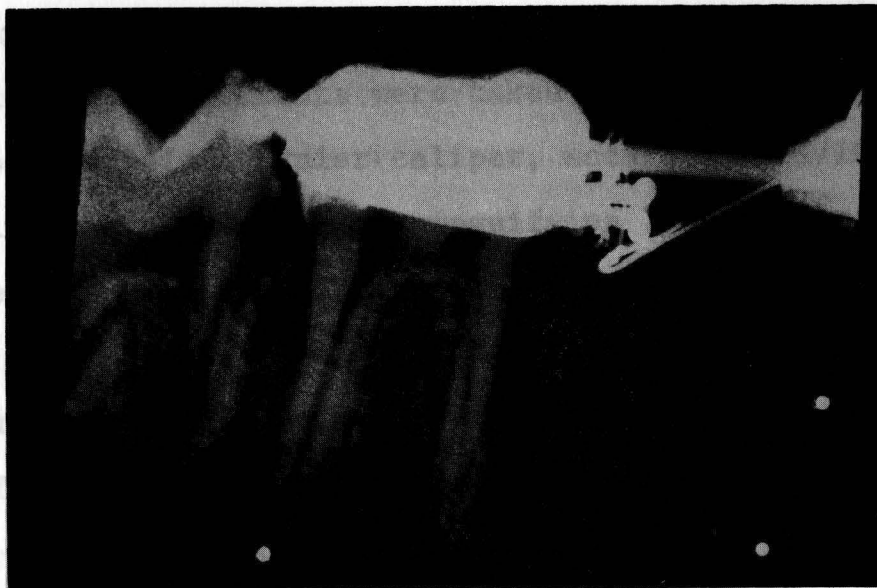


FIGURE 19

The lateral petriogram roentgenograms taken during

the experiment (A) OCCLUSAL ROENTGENOGRAM (B) LATERAL ROENTGENOGRAM

on the tracing table and the distal roots of the second

teeth.

With these points correctly located on the graph paper, the film and graph paper were fixed together with "scotch" tape.

The phonograph needle test probe was again used to re-enter the pinhole perforations in the film and to puncture the drawing paper at the precise locations of each reference point. After each graph was perforated, the film was removed and each pinhole was circled with a sharp pencil and labelled with appropriate letters to identify the points. A separate sheet of graph paper was prepared for each occlusal film and identified with the animal and examination numbers.

All the measurements were taken by two operators. A Helios precision vernier caliper, accurate to 1/1000th of an inch, and a 3-1/2 inch magnifying lens were used to make measurements. The graph for each film was placed on the tracing table for maximum illumination of the points. The measurements for each point were made from the X'X and Y'Y coordinates and recorded.

(b) Method of Obtaining Measurements from the Lateral Periapical Roentgenograms:

The lateral periapical roentgenograms taken during the experiment were next considered. Each film was placed on the tracing table and the distal roots of the second

molar and second premolar were carefully identified with the aid of a 3-1/2 inch magnifying lens. A small pinhole was made directly through the distal apices. In addition, a pinhole was made on the second premolar, 4.5 millimeters upward from the distal root apex. This point of reference was centered on the root canal of the second premolar's distal root. The pinholes were made with a phonograph needle probe. A sheet of cellulose acetate was placed between the film and the tracing table to aid in maintaining a uniform size of perforation and to prevent damage to the tracing table. The perforations were assigned letters alpha and beta for the second premolar. The alpha marking was the distal root apex and the beta marking was 4.5 millimeters upward from the distal root apex as shown in Figure 18.

A sheet of Keuffel and Esser graph paper was used to refer the pinhole perforations to a system of rectangular coordinates. The graph paper was divided into five sections and a system of X'X and Y'Y coordinates were set in each section. Each section was designated for the periods that the records were taken, namely the first, fourth, eighth, sixteenth, and twenty-third days. One sheet of graph paper was used to record the reference marks of the amalgam markers on the treatment side while a second sheet was used for recording the reference side (non-treatment side).

Each mandibular periapical film was again returned to the tracing table, this time with a sheet of the graph paper between the sheet of cellulose acetate and the film. The graph paper was carefully oriented so that the molar distal root apex perforation was superimposed on the origin of the coordinate system. The image of the lingual arch wire was positioned parallel with the X'X coordinate. This placed the premolar root apex perforation into quadrant I. With these points correctly located on the graph paper, the film and graph paper were fixed together with "scotch" tape.

The phonograph needle test probe was again used to re-enter the pinhole perforations in the film as seen in Figure 19, and to puncture the drawing paper at the precise location of each reference point. After each graph was perforated, the film was removed and each pinhole was circled with a sharp pencil and labelled with appropriate letters for identification of the points. One sheet of graph paper was used for all the readings of the active side and a separate sheet was used for all the readings on the reference side.

All the measurements were taken independently by two operators. A Helios precision vernier caliper, and a 3-1/2 inch magnifying lens were used to make the

measurements, of the distances of points "alpha" and "beta" from the X and Y coordinates. The graph for each film was placed on the tracing table for maximum illumination.

CHAPTER V

EXPERIMENTAL RESULTS

A. Physical Findings:

1. Reducing the Data:

The process of reducing the data to findings began when the laboratory phase of the experiment was completed. This consisted of taking measurements from the roentgenograms as described in Chapter IV, Methods and Materials. The data collected for each animal were recorded on charts, samples of which are found in Table II and Table III. Table II, represents data collected for one of the monkeys. This table represents the findings derived from the occlusal roentgenograms. Table III, is data collected for an animal on the lateral roentgenograms. The following conditions will be noted in each table: operators making measurements; side (treatment or control); number of the monkey; reference points; time of the examination; and coordinate axes.

Measurements of changes in tooth position were made on the roentgenograms on the day the experiment was begun and on the fourth, eighth, sixteenth, and twenty-third days. The changes in the locations of these teeth were plotted on a graph for these days. If the changes in location of these teeth are plotted on graphs having time

TABLE II

OCCLUSAL ROENTGENOGRAPHIC DATA SHEET

MONKEY IIIA

X READINGS:

<u>1st DAY</u>	<u>REFERENCE POINT</u>	<u>OPERATOR 1</u>	<u>OPERATOR 2</u>
	B	11.30	11.25
	C	13.25	13.20
	D	17.45	17.45
	E	17.45	17.40
	F	13.35	13.35
	G	11.15	11.15

TABLE III

LATERAL ROENTGENOGRAPHIC DATA SHEET
MONKEY 1A TREATMENT SIDE

EXAM.		X READINGS		Y READINGS	
<u>1st DAY</u>	<u>POINTS</u>	<u>OPER.1</u>	<u>OPER.2</u>	<u>OPER.1</u>	<u>OPER.2</u>
	a	14.00	14.00	.85	.80
	b	15.50	15.50	5.20	5.25
<u>4th DAY</u>					
	a	14.15	14.20	1.00	1.05
	b	15.45	15.45	5.40	5.45
<u>8th DAY</u>					
	a	14.40	14.40	1.20	1.20
	b	15.40	15.40	5.50	5.50
<u>16th DAY</u>					
	a	14.55	14.50	1.30	1.30
	b	15.30	15.30	5.70	5.70
<u>23rd DAY</u>					
	a	14.80	14.80	1.30	1.35
	b	15.25	15.20	5.75	5.75

as the horizontal or "x" axis, the line connecting these locations reveals the trend of tooth movement.

2. Testing the Stability of the Anchor Units:

Since this experiment dealt with a method of physically assessing the movement of teeth from roentgenograms, a test was devised for ascertaining the stability of the anchor units. This was performed as follows: Points A, D, E, and H, which were described in detail in Chapter IV, were the corner points of the anchor unit. Points A (left side) and H (right side) were the second molar teeth, while D (left side) and E (right side) were the first premolars. The second premolar, the tooth which was being moved by the orthodontic appliance, was between these teeth. To put it another way, these points A, H, D, and E were the anchor teeth to which the appliances were attached to move the second premolar teeth. Point H was always located at the intersection of the "x" and "y" axis, (Figure 19). Point A was always on the "y" axis above point H. If there was no experimental error and no change in the relations between these four corner points, these points would not move and consequently remain constant from one examination to the next. Therefore, a change in position of the locus of the three points A, D, and E, would be indicative of experimental error and actual movement

of these three anchor points. The standard deviations of the respective values of these points was a measure of the degree of movement of these points. The points shown on the chart were the "x" and "y" values for each point for each roentgenograms. After the calculations were completed, the average standard deviation was found to be .064 mm., as seen in Table IV. The 99% confidence limits indicated that a point in the anchor unit lay in a square measuring .32 x .32 mm. This square was the measure of uncertainty in the location of the anchor points and this could be attributed to experimental error rather than movement of the anchor points. It can be concluded that the anchor points were relatively stable.

3. Analysis of Variance for the Occlusal Roentgenograms:

The Analysis of Variance was used to analyze the data from the occlusal roentgenograms. This analysis is a useful technique for the statistical evaluation of normally distributed numerical data. In essence, this analysis partitions the sum of squares due to all sources of variation and those sums attributable to each source. In addition, it provides a measure of experimental error in the experiment. The main sources of variation were Operators, Animals, Sides, Points, and Examinations. There were two

TABLE IV

STABILITY OF THE ANCHOR UNIT POINTS

STANDARD DEVIATIONS

	<u>MONKEY IA</u>	<u>MONKEY IILA</u>
Y _a	.06818	.06289
Y _d	.06245	.06760
X _d	.05656	.06708
Y _e	.05916	.07293
X _e	.07582	.06123
Sum of squares:		.1726
Degree of freedom:		49
Total mean square:		.0035
Square root:		.059 mm.
99% confidence limits or uncertainty of a point:		\pm .164 mm.

Operators, two Animals (each animal had two Sides), three Points (two amalgam fillings in each mandibular second premolar and one on the second molar) on each side, and five serial Examinations. The animals represented a random sample. The other sources represented complete distributions.

The error variance or the estimate of experimental error was .0025 and the standard error of measurement was the square root of this number or plus or minus .0500 mm. The 99% confidence limits of the distribution of experimental errors were plus or minus .129 mm. This is equivalent to about three times the least count of the measuring instrument. The least count of the measuring instrument is .05 mm. which is the smallest readable increment on its scale. This amount of experimental error was accepted as being reasonable for these conditions of measurements.

The results of the complete statistical analysis are shown in Table V. These will not be discussed in detail but some explanatory remarks are necessary, however, for a clearer understanding of the results. Among the main sources of variation, there was a significant difference between the jaws of the two animals as was expected. The monkeys did not have identical growth patterns and arch forms so their mandibular dimensions were different. The

TABLE V
ANALYSIS OF VARIANCE
(OCCLUSAL ROENTGENOGRAMS)

SOURCES	D.F.	S.S.	M.S.	V.RATIO	SIGNIFICANCE
OPERATORS	1	.0017	.0017		N.S.
ANIMALS	1	12.6425	12.6425	44.26	19.00**(5%)
SIDES	1	.0152	.0152		N.S.
POINTS	2	799.1425	399.5712	1400.03	99.00***(1%)
EXAMINATIONS	4	.8439	.2109	84.36	3.54**(1%)
O x A	1	.0017	.0017		N.S.
O x S	1	.0017	.0007		N.S.
O x P	2	.0004	.0002		N.S.
O x E	4	.0007	.0002		N.S.
A x S	1	.3360	.3360		***
A x P	2	.5708	.2854		***
A x E	4	.0016	.0004		N.S.
S x P	2	.1901	.0905		N.S.
S x E	4	.2543	.0635	25.40	7.01***(1%)
P x E	8	.0377	.0047		N.S.
O x A x S	1	.0009	.0009		N.S.
O x A x P	2	.0019	.0009		N.S.
O x A x E	4	.0046	.0011		N.S.
O x P x E	8	.0069	.0009		N.S.
O x S x P	2	.0006	.0003		N.S.
O x S x E	4	.0025	.0006		N.S.
A x P x E	8	.0114	.0014		N.S.
A x S x P	2	.0244	.0122		***
A x S x E	4	.0030	.0007		N.S.
S x P x E	8	.0701	.0088		N.S.
SUBTOTAL	81	814.1661			
RESIDUAL	38	.0959			
TOTAL	119	814.2620			

STANDARD DEVIATION OF ERROR = \pm 0.500 mm. and the 99%

CONFIDENCE LIMITS ARE = \pm .129 mm.

*** = HIGHLY SIGNIFICANT VARIANCE RATIO

N.S. = NON-SIGNIFICANT VARIANCE RATIO - ALL LESS THAN 1

various points were located in the teeth as previously stated and hence, their coordinates were different. They had to show a highly significant variability. Since the positions of the teeth changed between examinations, this would naturally result in a highly significant variability. In this experiment, however, the important findings lay not in the main sources of variation but rather in the way each influenced the other, that is their interaction.

The results of the Analysis of Variance are shown by graphs. The significant interactions were plotted to represent the variation that resulted between two main sources.

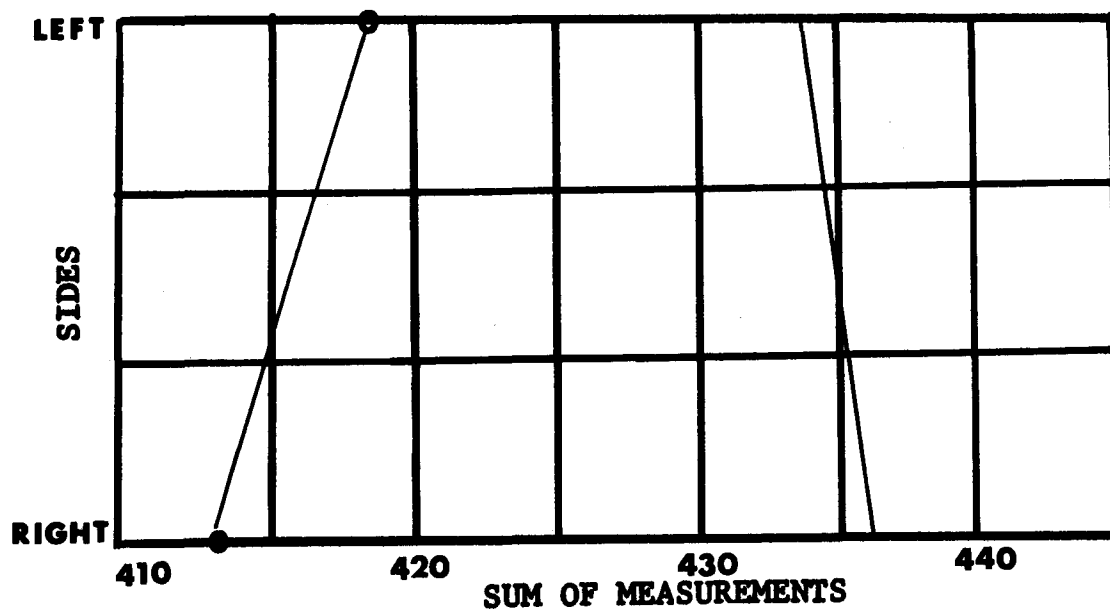
The highly significant interaction of Animals x Sides indicated that the difference between the treatment and reference sides of monkey IIIA was greater than the difference between the two sides of monkey IA as shown in Figure 20. In the graph, the lack of parallelism of the two lines indicates a statistically significant interaction. If the lines were parallel, the interaction would simply be another measure of experimental error.

The highly significant interaction of Animals x Points indicated that the distance between the points on the first premolar and second premolar was greater on

ANIMALS X SIDES

INTERACTION

ANIMAL



○ — ○ M III A
— M I A

FIGURE 20

monkey IIIA than on monkey IA as shown in Figure 21.

The last significant two factor interaction was Sides x Examinations. It is readily apparent from Figure 22, that there was distal movement of the teeth on the treatment side of both animals between the examinations. There was also a slight distal drift of the teeth on the reference side.

4. Analysis of Variance of the Lateral Roentgenograms:

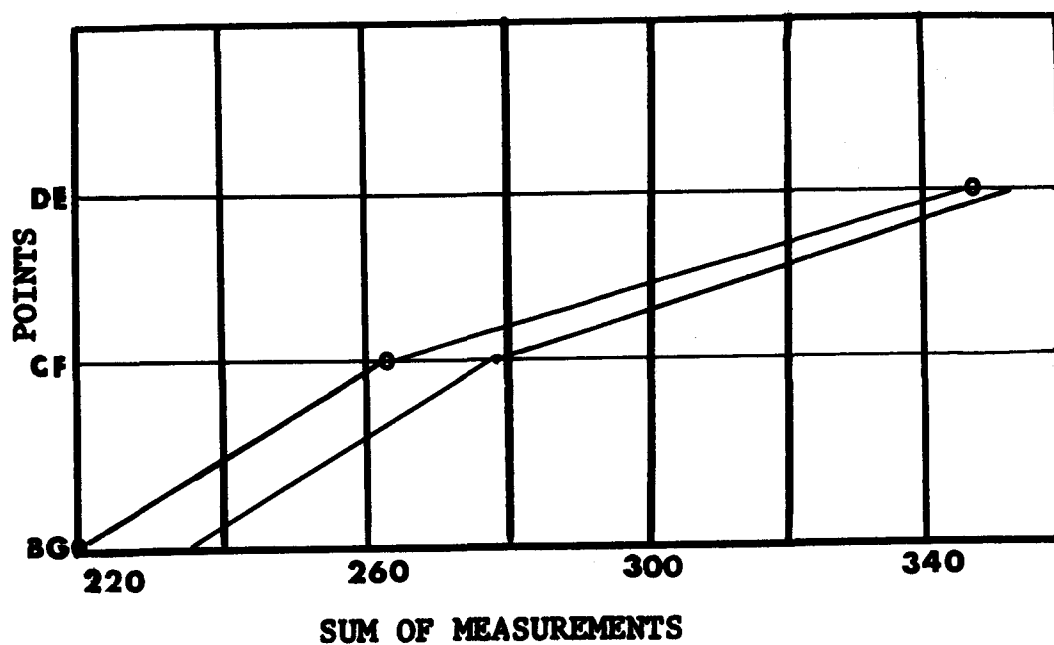
The Analysis of Variance was also used to analyze the data obtained from the lateral roentgenograms. The main sources of variation were Operators, Animals, Sides, Points, and Examinations. As seen in Table VI, the "Analysis of Variation Table" records the sources of variation such as two Operators, two Animals, two Sides to each animal, two Points on each side of an animal (alpha and beta), and five serial Examinations. The animals again represented a random sample from a larger population while other sources of variation represented complete distributions.

The error variance or the estimate of experimental error was .0224 obtained from 48 degrees of freedom. The standard error of measurement was obtained by taking the square root of .0224 which was plus or minus .0678 mm.

ANIMALS X POINTS

INTERACTION

ANIMALS



ANIMALS:

o — o M III A

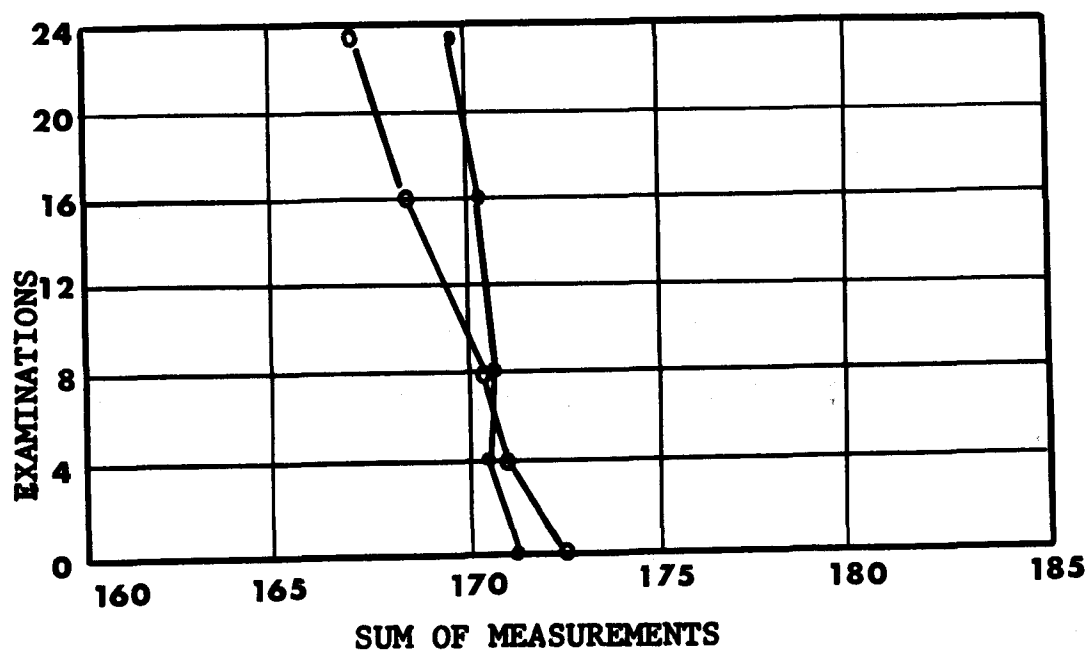
. — . M I A

FIGURE 21

SIDES X EXAMINATIONS

INTERACTION

SIDES



o—o Active Side
— Reference Side

FIGURE 22

TABLE VI
ANALYSIS OF VARIANCE
(LATERAL ROENTGENOGRAMS)

SOURCES	D.F.	S.S.	M.S.	V.RATIO	SIGNIFICANCE
OPERATORS	1	.0025	.0025		N.S.
ANIMALS	1	6.3000	6.3000	281.2	161**(5%)
SIDES	1	10.0465	10.0465		N.S.
POINTS	1	30.0738	30.0738		N.S.
EXAMINATIONS	4	.1532	.0383		N.S.
O x A	1	.0001	.0001		N.S.
O x S	1	.0026	.0026		N.S.
O x P	1	.0025	.0025		N.S.
O x E	4	.0027	.0006		N.S.
A x S	1	4.5363	4.5363		N.S.
A x P	1	2.4675	2.4675		N.S.
A x E	4	.0202	.0050		N.S.
S x P	1	.4575	.4575		N.S.
S x E	4	.2293	.0573		N.S.
P x E	4	1.8108	.4527	238.26	437*** (1%)
O x A x S	1	.0002	.0002		N.S.
O x A x P	1	.0003	.0003		N.S.
O x A x E	4	.0019	.0005		N.S.
O x P x E	4	.0013	.0003		N.S.
O x S x P	1	.0009	.0009		N.S.
O x S x E	4	.0004	.0001		N.S.
A x P x E	4	.0288	.0072		
A x S x P	1	3.7196	3.7196		***
A x S x E	4	.0051	.0013		N.S.
S x P x E	4	.4348	.1087	4.85	3.74*** (1%)
SUBTOTAL	58	60.2985			
RESIDUAL	21	.0390			
TOTAL	79	60.3375			

STANDARD DEVIATION OF ERROR = \pm .0678 mm. and the 99%

CONFIDENCE LIMITS ARE = \pm .187 mm.

*** = HIGHLY SIGNIFICANT VARIANCE RATIO

N.S. = NON-SIGNIFICANT VARIANCE RATIO - ALL LESS THAN 1

The 99% confidence limits of the distribution of experimental error were plus or minus .187 mm. This is equivalent to three to four times the least count of the measuring instrument. The least count of the measuring instrument is .05 mm. which is the smallest readable increment on its scale. This amount of experimental error was again accepted as being reasonable for these conditions of measurement.

An assessment of the "Analysis of Variance Table" revealed that only Animals were a significant source of variation. This was attributed to the differences of mandibular jaw dimensions and arch forms. Looking at the table, one might conclude that Sides and Points would be significant sources of variation. These were found to be non-significant sources of variation when tested against the reference designated for their comparison. The important findings lay not in the main sources of variation but rather in the interaction between these sources of variation.

The highly significant interaction of Points x Examinations, seen in Figure 23, indicated that the difference between the alpha reference point was greater than the beta reference point. This meant that the apex or alpha point moved more than the beta point or a point on the root

**POINTS X EXAMINATIONS
INTERACTION**

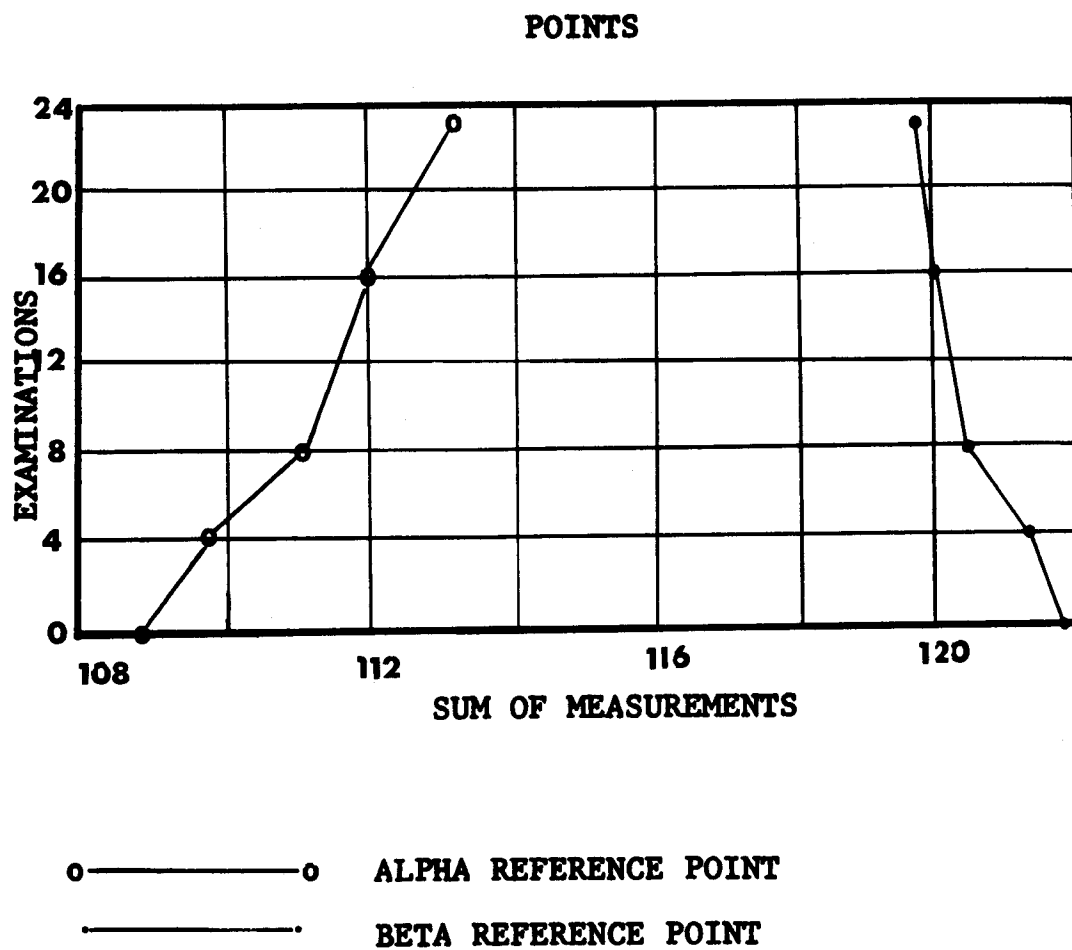


FIGURE 23

4.50 mm. cervically from the apex. In addition, there was a mesial movement of the alpha point and a distal movement of the beta point.

5. Physical Assessment of Tooth Movement:

The amount of tooth movement on the treatment and control sides at each experimental period was evaluated from the original data of the occlusal and lateral radiographs. Movements of the mandibular second premolar were ascertained in three planes of space; horizontal, vertical, and transverse. Graphs were used to illustrate the direction and magnitude of the tooth movement found on the radiograms. In all of the graphs, the horizontal scale indicated the time interval between the taking of each set of records. The plotted points represented the direction in which the second premolar tooth moved from one experimental period to the next. The movements of the teeth were as follows:

(a) Distal Movement of the Crown:

The occlusal radiographs were used to assess the distal movement of the crown of the mandibular second premolar. The amount of distal movement of this tooth from zero to twenty-three days was calculated by averaging the measurements of two operators. Measurements were made

from the "x" axis on the rectangular coordinates. In the graph (Figure 24), showing movements of the crown of the mandibular second premolar, a rising line indicates distal tipping. During the twenty-three days of the experimental period, the crown of monkey IA and monkey IIIA moved one half of a millimeter distally.

(b) Rotation:

With the appliance on the lingual surface several millimeters from the long axis of the tooth, a rotation of that tooth was anticipated. This rotation was assessed from zero days to twenty-three days. The data obtained from the occlusal roentgenograms for the treatment side indicated the mandibular second premolar rotated 2.5° in monkey IA and 3.2° in monkey IIIA. The manner in which this was calculated will be described in the following paragraph.

The sample values were taken from monkey IIIA, on the last day of the experiment prior to sacrificing the animal. For this computation "A" is the alpha reference point and "B" the beta reference point. All measurements are in millimeters.

	<u>A</u>	<u>B</u>
Y	1.45	1.30
X	14.25	11.90

DISTAL MOVEMENT OF THE
CROWN

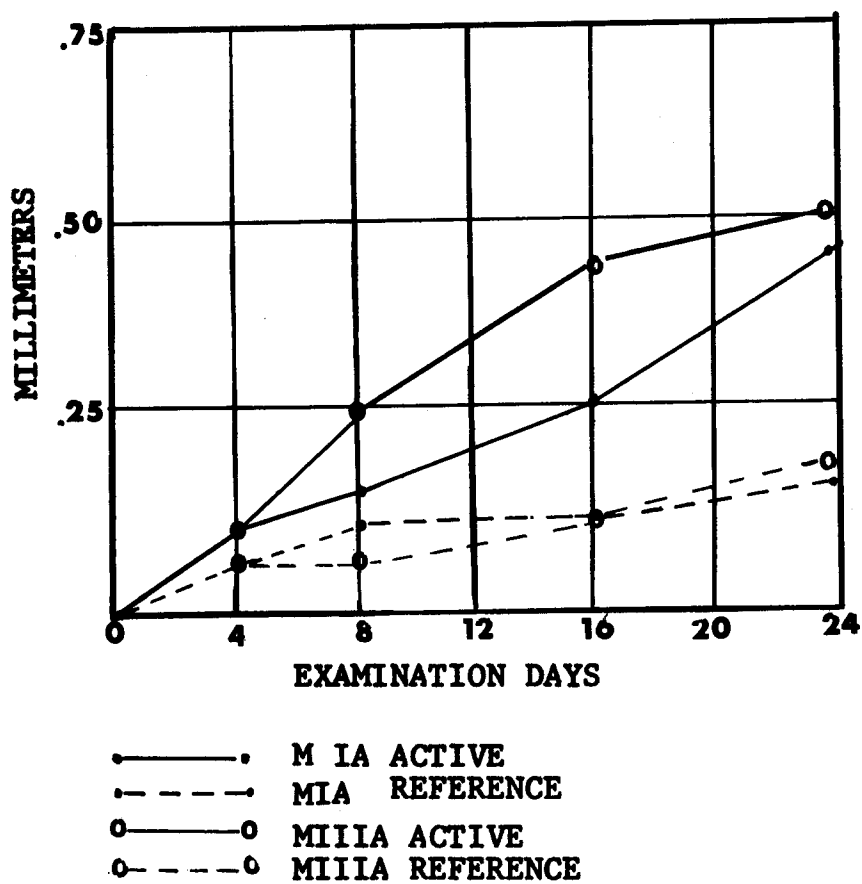


FIGURE 24

The first step in this problem is to determine trigonometrically, the tangent of the premolar to the horizontal plane.

$$Y_A - Y_B = 1.45 - 1.30 \dots .15$$

$$X_A - X_B = 14.25 - 11.90 \dots 2.35$$

$$\begin{aligned} \text{tangent} &= \frac{\text{opposite side}}{\text{adjacent side}} \\ &= .06382 \end{aligned}$$

$$\begin{aligned} \text{arc tan} \\ .06382 &= 3^\circ 30' \end{aligned}$$

The graph in Figure 25, illustrates the original angular position of the premolar tooth on the treatment and control side at the onset of the experiment and during the experimental intervals. A rising line denotes distal rotation.

(c) Mesial Movement of the Root Apex or Alpha Point:

The lateral roentgenograms were used to assess mesial movement of the root apex of the mandibular second premolar. The amount of mesial movement of the apex from zero days to twenty-three days was calculated by averaging the measurements of two operators. Measurements of the alpha reference point taken from "x" axis indicated the amount of mesial movement of the root apex. Figure 26,

ROTATIONAL MOVEMENTS
OF
SECOND PREMOLARS

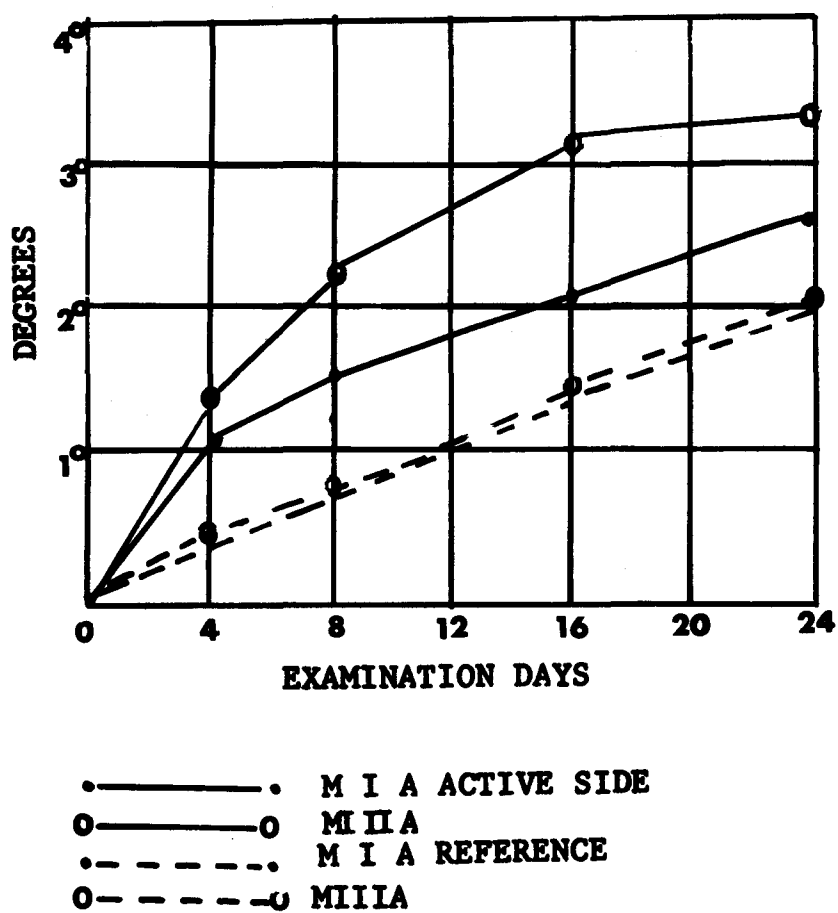


FIGURE 25

MESIAL MOVEMENT OF THE
ALPHA POINT

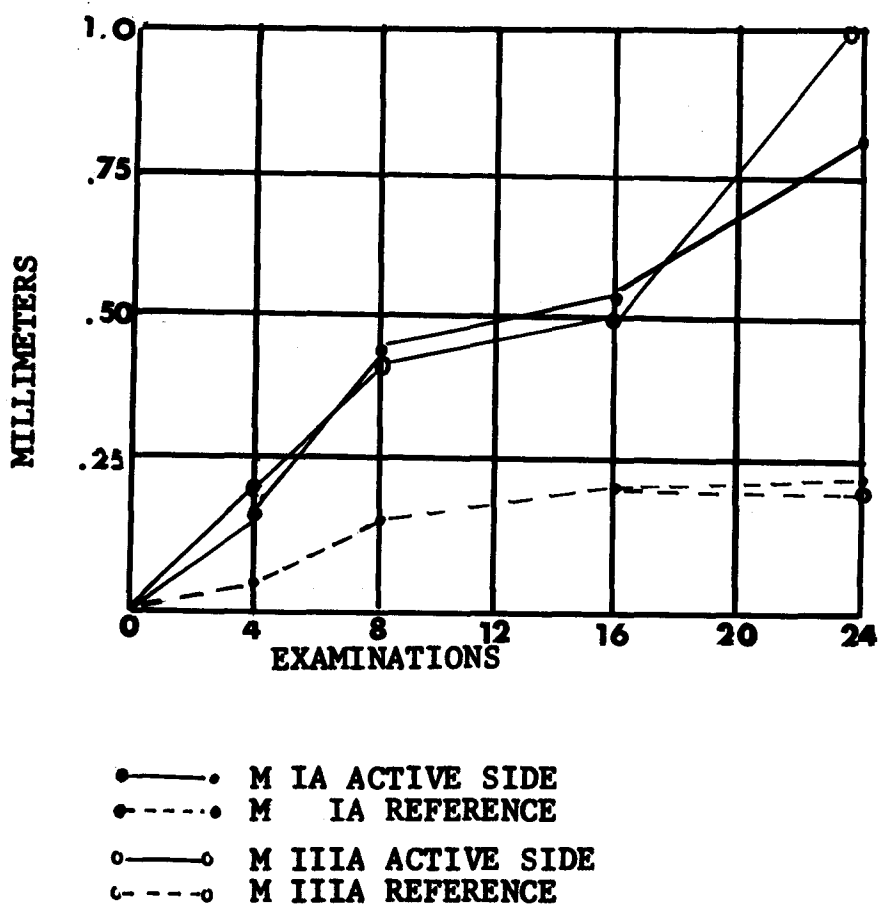


FIGURE 26

illustrates the amount of mesial movement in millimeters of the apex of the root. The horizontal scale of the graph indicates the days on which measurements were taken and the vertical scale indicates the position in millimeters of the root apex from the reference line. The points that were plotted represent the position of the tooth on each day stated. Five points were plotted for each tooth and a line was drawn through these points. The rising line seen on the graph indicates the apex of the mandibular second premolar moved in a mesial direction. The reference and treatment sides are plotted on the graph and thereby provide visual comparison of movement of the experimental tooth as compared with the reference or control side. In monkey IA there was .80 mm. of movement; monkey IIIA had 1.0 mm. The control side showed .20 mm. of mesial movement of the root apex (alpha point) in the two animals.

(d) Beta Point:

The direction of the second reference point on the premolar, beta, was also determined by its "x" values. Figure 27, illustrates the movement of the beta point. The horizontal scale of the graph indicates the day intervals on which the measurements were taken and the vertical scale represents the position in millimeters of the beta point from the reference line. An increasing line in

DISTAL MOVEMENT OF THE BETA POINT

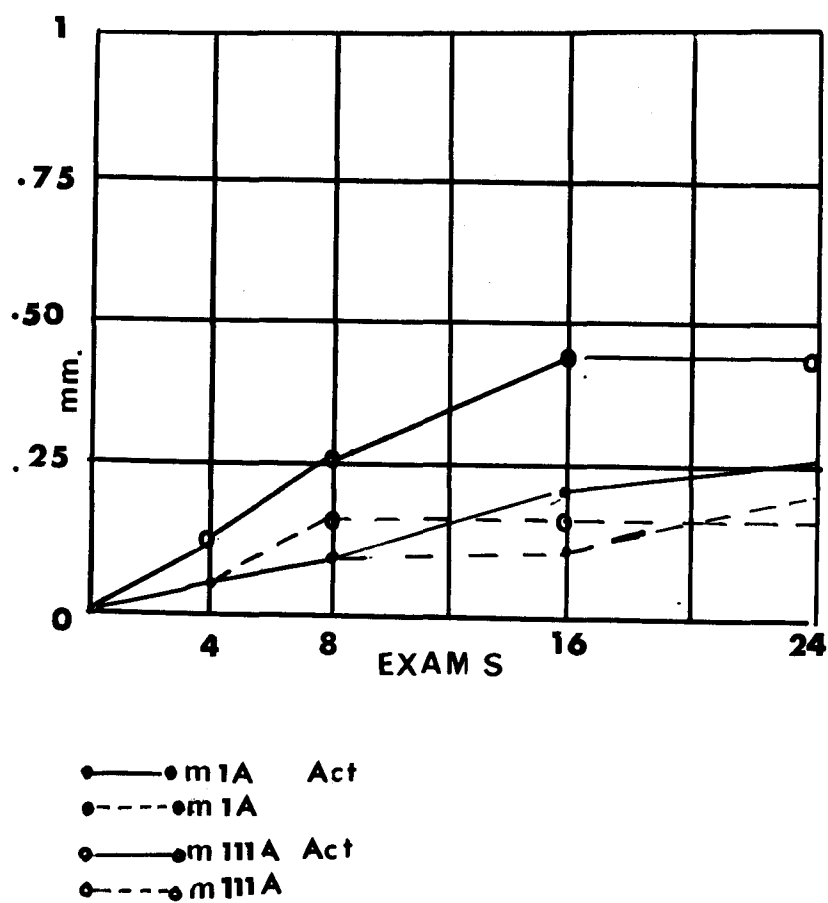


FIGURE 27

the graph means that beta point moved in a distal direction showing the center of tipping lay somewhere in the root.

(e) Extrusion:

The rectangular coordinates were also used to ascertain the amount of extrusion of the second premolar taking place during the experiment. In order to assess extrusion, the "y" readings of alpha and beta were measured, and plotted in Figure 28. Extrusion occurred on the reference and treatment sides alike. This was to be expected because the posterior teeth were kept out of occlusion with a maxillary anterior bite plane.

(f) Angular Changes:

The degree of change in the position of the mandibular second premolar was determined for each examination of the treatment and control sides of monkey IA and monkey IIIA. The angular changes were plotted (Figure 29). The horizontal scale of the graph shows the day intervals on which the roentgenograms were taken, and the vertical scale is the position in degrees of the second premolar measured from a horizontal line. It is apparent there were angular changes on the control and treatment sides. The slopes of the rising lines express the difference in the angular positions of the respective

EXTRUSION MOVEMENTS

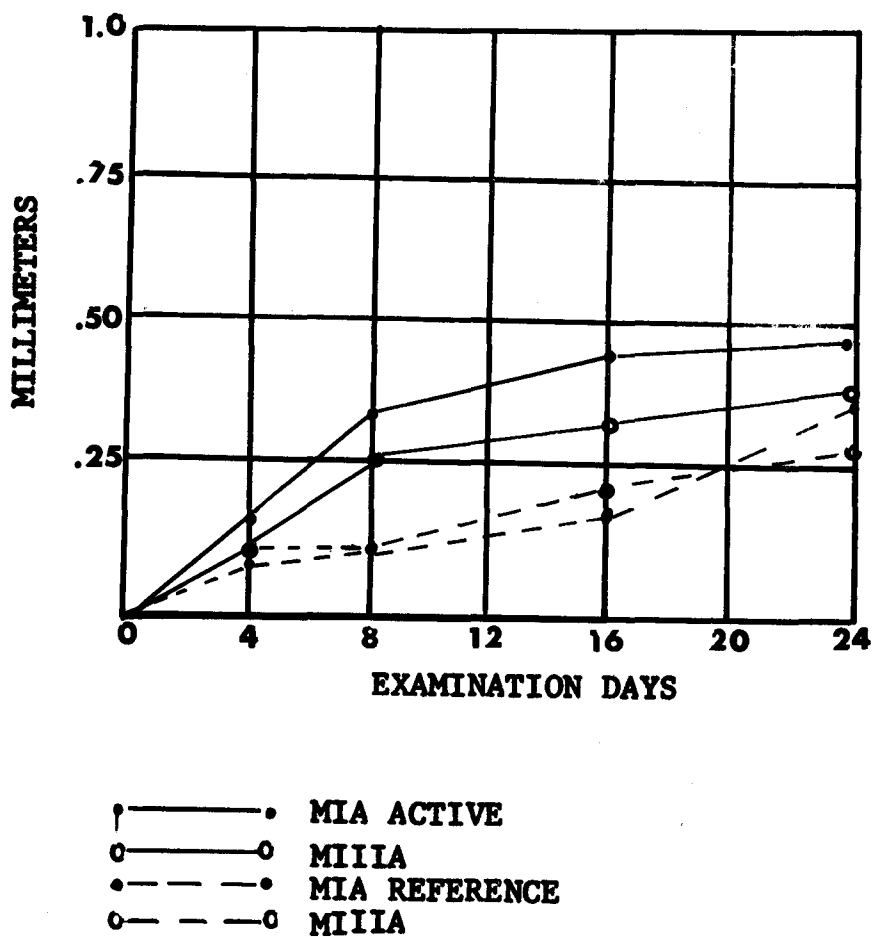


FIGURE 28

**ANGULAR CHANGES
OF
THE SECOND PREMOLAR TOOTH**

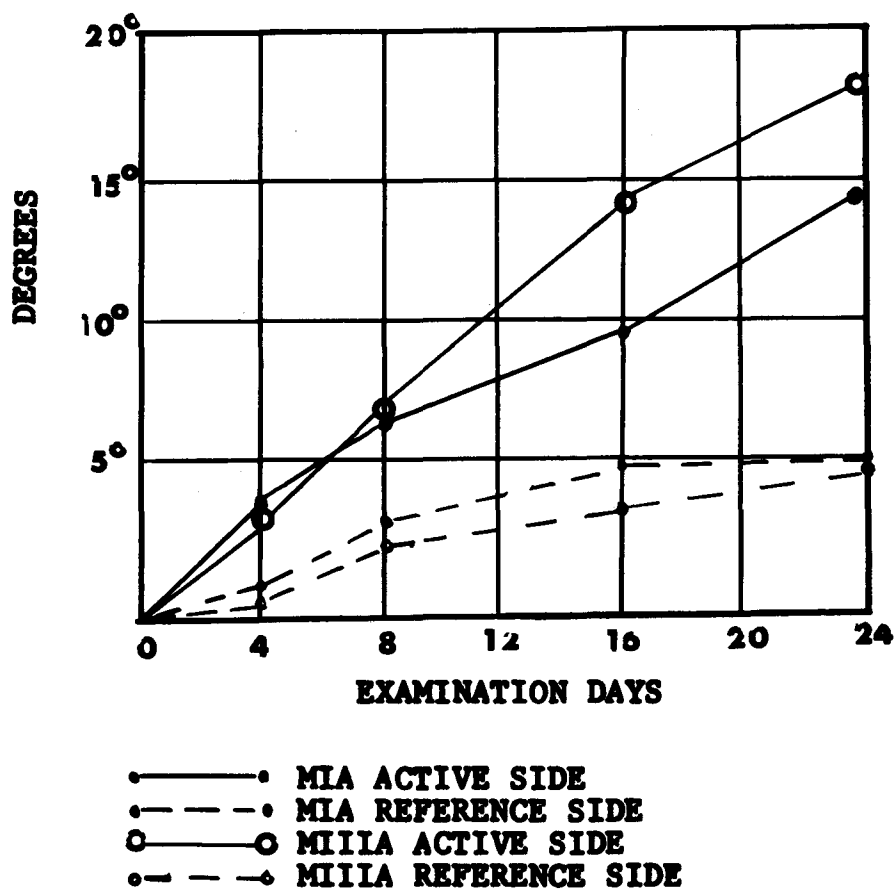


FIGURE 29

teeth. The treatment sides had a greater angular change than the reference side. The angular positions for each experimental interval were determined by the calculation of their tangent values in the following manner:

	Point X	Alpha Y	Point X	Beta Y
Monkey IA treatment side	14.00	5.22	15.52	.825

$$\text{tangent} = \frac{\text{opposite}}{\text{adjacent}}$$

$$\text{tangent} = \frac{Y_a - Y_b}{X_a - X_b} = \frac{5.22 - .825}{15.52 - 14.00}$$

$$\text{tangent} = \frac{4.40}{1.52} = 2.8941$$

$$\text{arc tan} \\ 2.8941 = 70^{\circ} 56'$$

Table VII, lists the angular positions of the mandibular second premolars for each experimental interval on the two monkeys.

(g) The Effective Axis of Tipping:

The effective axis of tipping of the mandibular second premolar was determined by calculating algebraically where the central axis of the premolar in the first examination intersected with the central axis of the same tooth on the twenty-third day. A calculation was then performed to reveal the location of the effective axis of tipping above the apex of the root. The calculation

TABLE VII

CHANGES OF ANGULAR POSITION OF THE
PREMOLAR TO REFERENCE PLANE

ARC TAN CALCULATIONS

<u>MONKEY IA</u> <u>TREATMENT SIDE</u>	<u>EXAMINATION</u> <u>DAY</u>	<u>DEGREES</u>
	0	70.2
	4	73.7
	8	76.2
	16	79.6
	23	84.1

<u>MONKEY IIIA</u> <u>TREATMENT SIDE</u>	<u>EXAMINATION</u> <u>DAY</u>	<u>DEGREES</u>
	0	67.2
	4	70.6
	8	73.4
	16	81.3
	23	84.5

revealed the position of the effective axis of tipping to be 2.65 mm. for monkey IA and 2.74 mm. for monkey IIIA above their respective apices.

The effective axis of tipping was calculated by using the coordinates of alpha and beta of an animal on the treatment side. This calculation required the writing of two equations and solving of the simultaneous equations. The first equation was obtained from the coordinate values from the first day of experimentation. The second equation was obtained from the coordinate values from the twenty-third day. The next step was to solve the simultaneous equations representing the position of the center of tipping on the first day and the center of tipping on the twenty-third day.

Monkey IA is used as an example for the calculation of the effective axis of tipping. This calculation was performed in the following manner:

Working equation:

$$Y - Y_1 = \frac{Y_2 - Y_1}{X_2 - X_1} (X - X_1)$$

The symbols represent coordinates of the alpha and beta points.

Y_1 = alpha Y readings

X_1 = alpha X readings

Y_2 = beta Y readings

X_2 = beta X readings

First Examination T=0:

I.

ALPHA

BETA

Y_1	X_1	Y_2	X_2
.825	14.00	5.225	15.50

$$Y - .825 = \frac{5.225 - .825}{15.50 - 14.00} (X - 14.00)$$

$$Y - .825 = \frac{4.42}{1.50} (X - 14.00)$$

$$Y - .825 = 2.946 X - 41.254$$

$$Y = 2.946 X - 40.429$$

II. Twenty-third day T=23:

ALPHA

BETA

Y_1	X_1	Y_2	X_2
1.325	14.80	5.75	15.20

$$Y - 1.325 = \frac{5.750 - 1.325}{15.20 - 14.80} (X - 14.80)$$

$$Y - 1.325 = \frac{4.425}{0.40} (X - 14.80)$$

$$Y - 1.325 = 11.062 (X - 14.80)$$

$$Y = 11.062 X - 162.392$$

The next step is to solve the simultaneous equations representing the position of the center of tipping in the first day and the twenty-third day of treatment of the mandibular second premolar.

$$Y = 2.946X - 40.429$$

$$\underline{Y = 11.062X - 162.392}$$

$$0 = (-) 8.116X - (-) 121.963$$

$$X = \frac{12.963}{8.116} = 15.02 \text{ mm.}$$

Substitute the calculated value of "X" into the second equation:

$$(t=0 \text{ to } T=23):$$

$$Y = 11.062X - 162.392$$

$$Y = 11.062 \times 15.02 - 162.392$$

$$Y = 166.121 - 162.392$$

$$Y = 3.729$$

To determine the location of the effective axis of tipping above the apex of the root, the following calculations were made:

$$T = 23 \quad 1.325$$

$$T = 0 \quad \underline{.825}$$

$$2.150 \div 2 = 1.075$$

This is the average alpha readings for the first and twenty-third days.

The effective axis of tipping above the apex of the root of monkey IA was the following:

$$3.729 - 1.075 = 2.65 \text{ mm.}$$

B. Changes in the Architecture of the Alveolar Process:

The lateral roentgenograms were used to interpret the dentoalveolarperiodontal environment during the

execution of this experiment. They provided a source of information which was used to study the changes in the alveolar process after orthodontic stresses have been placed on the teeth.

Lateral roentgenograms were taken of the treatment and control side on the first, fourth, eighth, sixteenth, twenty-third, and twenty-eighth days. The experiment terminated on the twenty-eighth day. In general, the roentgenograms revealed the following: the interradicular crest of the second premolars; the distal root of the mandibular second premolars; the first molar extraction sites; entire mandibular second molars; and the mesial half of the still unerupted third molars.

1. Monkey IA

Examination of the architecture of the alveolar spongiosa on the treatment and reference sides were similar when the experiment was started. The trabeculation gave a heterogeneous appearance, being closely knit with few horizontal trajectories. The alveolar spongiosa was denser at the apex of the posterior teeth than toward the alveolar crest. The cribriform plate (lamina dura) appeared like a narrow opaque layer around the distal root of the mandibular second premolar. The periodontal space around the distal root of the premolar on the treatment and

reference side was of uniform thickness. The cribriform plate of the mandibular second molar was denser on the distal root and interradicular crest, and very thin on the mesial root surface. The periodontal space appears wider from cementoenamel junction to a point near the middle of the root. On the treatment and control side, fragments of the distal root of the first molars may be observed. The first molars were fractured during the extraction of these teeth.

Roentgenographic changes on the fourth day of the experiment revealed the following; the architecture of the bone on the reference side was virtually the same as seen in the first roentgenograms. The periodontal space on the distal surface of the distal root of the second premolar was narrower and there was a wider space on the interradicular surface on the treatment side.

The most apparent differences on the eighth day were the widening of the periodontal space in the inter-radicular crest area of the premolar and the decrease in width of its cribriform plate on the distal surface of the distal root. New bone is forming around the distal root apex indicating this tooth is extruding.

On the sixteenth day, there was some distal tipping of the premolar observed on the reference side. This was

expected since the premolar had no appliance on it and could tip distally into the extraction site of the first molar. The width of the cribriform plate is less defined than in three previous examinations. In addition, there was evidence of extrusion of the second molar. New bone was forming around the apex of the mesial root. The periodontal space was wider in the interradicular area of the premolar on the treatment side.

The reference side showed little bone changes from the twenty-third to the twenty-eighth day. There were also virtually no discernible differences noted on the roentgenograms of the treatment side from the twenty-third to the twenty-eighth day. There was little increase in the periodontal space in the interradicular area of the second premolar. The periodontal space on the mesial side of the mesial root remained the same width when compared to the original roentgenogram.

2. Monkey IIIA

The roentgenograms taken on the first day of the experiment revealed that the architecture of the bone of monkey IIIA differed from monkey IA in that the alveolar bone was less dense. This was attributed to the greater number of horizontal trabecular trajectories of monkey IIIA and that the bone is not quite as closely knit as was found

in monkey IA. This animal was a younger animal as was shown in the crown height of the third molar and the stage of root formation.

There was a wide periodontal space on the mesial side of the mesial root of the second molars (treatment and reference sides). This indicated this tooth was moving distally. The most significant difference between the two monkeys was the root length of the second premolars. Monkey IIIA had roots that had a greater taper while the roots of monkey IA were one millimeter longer and not as tapered. In addition, the cribriform plate was thinner on the distal surface of the distal root of monkey IIIA.

The periodontal space on the entire surface of the interradicular crest of the second premolar was wider on the fourth day after initial activation of the orthodontic appliance. The periodontal space, however, on the mesial surface of the mesial root of the second molars showed no increase in width.

The most apparent changes between the roentgenograms taken on the fourth and eighth day were the reduction in the cribriform plate on the distal surface of the distal root of the premolar (treatment side), and formation of new bone at the apex. There was also some evidence of

distal tipping on the reference side. This was accompanied by a reduction in the thickness of its cribriform plate.

Roentgenograms taken on the sixteenth day of the experiment revealed that new bone formed around the mesial root apex of the second molar on the treatment and reference sides. This indicated there was some extrusion of these teeth. The cribriform plate on the distal surface of the distal root of the second premolar on the treatment side was reduced to a narrow width.

On the twenty-third day, the roentgenograms revealed a wider periodontal space in the interradicular crest area of the second premolar. The cribriform plate is not seen giving further evidence distal tipping resulted.

C. Moment of Force:

A study was made of the actual moment of the force of the two coil springs for each animal from the first to the twenty-third day. This was done in the following manner: A reference was made to the load deflection chart prepared in Chapter IV. The following chart relates the angular changes that were obtained in the experiment on the given examination days to the calculated moment of force:

<u>Monkey IA Examination</u>	<u>Degree Change</u>	<u>Moment (gm.mm.)</u>
t=0	0.0	445.5
t=4	3.5	415.7
t=8	6.0	393.4
t=16	9.4	360.3
t=23	14.0	317.6

<u>Monkey IIIA Examination</u>		
t=0	0.0	477.8
t=4	3.4	448.9
t=8	6.2	423.5
t=16	14.1	348.9
t=23	17.3	311.8

CHAPTER VI

DISCUSSION

In the past, orthodontic literature has placed great emphasis on appliances and perhaps rightfully so because they are tooth-moving devices. Empiricism concerning orthodontic forces derived from various appliances has been the rule rather than the exception. Occasionally, biologically incompatible appliances have been used because tradition has decreed that they be used. One big reason for this empiricism has been the timidity of the specialty to realize that an orthodontist is in effect a highly specialized biologic engineer whose skills must be developed in terms of force systems and that the force systems should dictate appliance design.

This thesis deals with one of many possible force systems that might be used in orthodontics. This system is, however, a very unusual one for producing the most common type of tooth movement; namely, tipping.

When a tipping force is applied to the crown of a tooth, it is not the only force acting on the tooth. A second force system is immediately developed by the biologic environment of the tooth; this is a resisting force system. Generally, these resisting systems consist of

moments or couples as pointed out by Burstone (1962), Haack and Weinstein (1963), Jarabak and Fizzell (1963), and Geigel (1965). They may also contain combinations of forces and couples or just combinations of forces. According to the principles of analytical mechanics the application of a single pushing force to the crown of a tooth will result in the development of a moment of force in the periodontal ligament. This can be resolved into a resisting force and couple. It is difficult to separate a resisting force and couple in the case of the single pushing force. This difficulty caused early investigators like Sandstedt (1903), Oppenheim (1911), Case (1921), and Schwarz (1928), to do considerable speculating even though they had only an intuitive grasp of the problem. These men had a justifiable interest in the location of the center of tipping but they did not understand the mechanics that would explain the resisting force systems and the resulting center of tipping. The center of tipping was for many years a center of controversy. Finally the explanation of the applicable mechanics appeared in a book by Jarabak and Fizzell (1963).

The application of a couple to the crown of a tooth results in the development of a resisting couple. This couple will have the centroid of projected root area as

its central axis and it will be equal and opposite to the applied couple. This fact provides a means of knowing the magnitude and sense of the resisting couple. Such knowledge was not available to the early investigators mentioned before and this explains the reason for selecting a pure couple as the choice of force system for this research.

The concept of a couple has appeared in the literature on few occasions and at widely spaced intervals. Fish (1917), an analytical engineer, addressing an orthodontic society described a couple as "two forces which are equal and opposite and there is a distance between them". He further stated "that the effect of a couple is to move the apex of the root in a direction opposite to the applied force". His accurate description of this force system aroused no analytical approaches to the understanding of tipping and empirical approaches remained the popular ones for forty-five years. Burstone (1962), states that "if a pure couple is placed anywhere on a tooth, a center of rotation occurs at centroid". Haack and Weinstein (1963), applied pure couples on a two-dimensional model and found the center of tipping to be somewhat apical to the center of the root. Jara-bak and Fizzell (1963), and Geigel (1965), using models

analogues studied stresses acting on the root of a tooth with the application of a tipping couple to its crown. These theories have not been tested clinically.

In beginning this work, several designs were studied in an attempt to find the best device to create a pure couple. The flat coil spring having a very low magnitude of torque was selected because it was felt it would fulfill the biologic as well as the mechanical objectives of the experiment. This spring was designed much like the main spring of a watch but it was made with two active portions that were balanced. A single spring would produce a moment of force while two springs balanced around a common center would produce a couple. Such a device could be described as a pure couple if there were absolutely no other force communicated through it to the tooth. In practice, however, the two lateral arms had to be affixed to adjacent teeth and they could have transmitted some mesial-distal or buccal-lingual forces to the second premolar. A lack of perfect balance between the two halves of the coil spring could have resulted in either an intrusive or an extrusive force on this tooth. These practical conditions emphasize the difficulty in developing a pure couple.

While the applied couple was nearly a pure couple,

there was another difficulty that was recognized in the attempt to limit the force system on the tooth to just a pure couple. The difficulty was the impracticality of eliminating all extraneous forces. To eliminate these extraneous forces it was necessary to place a bite plane on the maxillary anterior teeth. Taking the posterior teeth out of occlusion eliminated frictional forces engendered in the functioning of the incline planes of the cusps. It did, however, allow forces within the periodontal environment to begin extruding the posterior teeth.

A search of the literature to find how earlier workers had measured tooth position and changes in this position revealed very little evidence of sophisticated measuring technique. There was absolutely no indication that the workers recognized the importance of both accuracy and precision in their measurements. Little help could be obtained from the researches of Reitan, Storey and Smith, and Heuttner and Young. Therefore, a new procedure was conceived and tested for this research. The occlusal radiographic method was checked for accuracy and precision while the lateral radiographic method was tested for precision only. A review of the literature reveals that Jeffry and Kostiwa were the only investi-

gators who used statistical means to ascertain the precision of their findings. The importance of this testing lies in the fact that it justified belief in both the feasibility and the reliability of the work and the measurements.

The use of our radiographic method to determine tooth position had a threefold purpose. First it allowed us to measure precisely changes in tooth position in three planes of space; horizontal, vertical, and transverse. Secondly, it provided a means of ascertaining alveolar changes resulting from a tipping of the tooth. Finally it made available numerical data that allowed analytical assessment and yielded the precision and accuracy that validated this work.

In looking at the graphs in the section "Physical Assessment of Tooth Movement" it is apparent the mandibular second premolar crown moved distally while the root apex moved mesially. This movement was anticipated because the moment of force for each spring was to produce a distal tipping movement. In the initial design and final construction of the spring, the total deflection of each spring was forty-five degrees and the working range was twenty degrees. Experimentally, it was found that the mandibular second premolar in monkey IIIA tipped

only fourteen degrees during the twenty-three days of experimentation. The full deactivation of the spring was not achieved because ill health of monkey IIIA compelled sacrifice of the animal on the twenty-third day. The appliance was removed from monkey IA on the twenty-eighth day after the tooth had tipped seventeen degrees.

A study of the changes in the architecture of the alveolar process confirmed the fact that the mandibular second premolar tipped distally. The periodontal space of the mandibular second premolar (treatment side) on the distal surface of the distal root became narrower and the interradicular surface became wider from the initial examination to the last day.

The purpose of assessing the degree of angular changes from one examination to the next in this study was twofold. First, it indicated the amount of tipping that occurred into an extraction site with a known moment of force applied during a given period of time. Second, the study of angular changes on the reference side demonstrated the amount of distal tipping of a tooth into an adjacent extraction site without the use of an orthodontic force. Such distal tipping of a tooth is common and is generally attributed to two factors. First, the soft tissue scar of the fibrous connective tissue of the extraction site

causes distal tipping and secondly, the tooth follows the path of least resistance.

Since measurements were made to record changes of tooth position resulting from the tipping movement, a test was performed to evaluate the stability of the anchor units. If there was mobility of the anchor units, all measurements of actual tooth movement would be invalid. It can be said from the outcome of this test that the anchor unit gave evidence of great stability and provided assurance of the validity of the actual distal movement of the teeth.

It has been previously mentioned that a pure couple has never been applied clinically to a tooth because it is practically impossible to eliminate the external forces that act on a tooth. Such extraneous forces would cause adverse movement apart from its pure tipping action. In addition to the distal tipping achieved in this study, an extrusive and rotational movement occurred on the mandibular second premolar on the treatment side. The extrusion was found on all the posterior teeth on the control (reference) and treatment sides. In attempting to eliminate functional interferences caused by steep cuspal incline planes of the posterior teeth, a maxillary anterior bite plane was used. This allowed the posterior teeth

to remain out of occlusion permitting them to extrude. Evidence of the extrusion of the posterior teeth was shown in the lateral radiographs during the sixteenth day on the two animals. With the use of an orthodontic appliance on the lingual surface of the premolar, a few millimeters from the long axis of the tooth, some rotation was anticipated. The findings revealed that distal rotation did occur but it was minimal. A possible explanation of the minimal rotation on the treatment side might be that the terminal ends of the spring, sliding through the oblong shaped eyelets, prevented a greater rotation of the second premolar tooth.

In Chapter V, it was stated that the deflection of the crown of the mandibular second premolar was in a distal direction while the deflection of the root apex was in a mesial direction. Naturally, this indicates that the tooth tipped distally about an axis somewhere along its root. The effective axis of tipping was determined by calculating algebraically where the central axis of the mandibular second premolar in the first examination intersected with the central axis of the same tooth in the last examination. Since the mandibular second premolars of monkey IA and monkey IIIA showed the axis of tipping was within the root, a calculation was performed to reveal

the location of the effective axis of tipping above the apex of the root. The calculation revealed the position of the effective axis of tipping to be 2.65 mm for monkey IA and 2.74 mm for monkey IIIA, above their respective apices.

The effective axis of tipping for the premolar in monkey IA was 43% of the length of the root or slightly less than one half the root length above the apex. Monkey IIIA had an effective axis of tipping for its premolar of 55% or slightly above the center of the root. A search of the literature reveals a difference of opinion as to the location of the center of tipping with the application of pure couples. Haack and Weinstein (1963), applying a clockwise pure couple to a geometric analogue observed that the center of tipping was a "little less than one half the root length from the apex". Burstone (1962), found that "if a pure moment (a couple) is placed anywhere on a tooth, a center of rotation occurs at the centroid of the tooth". Geigel substantiated Burstone's findings; moreover, he found that centroid was slightly above the middle of the root. What must be noted, however, is that Geigel found Burstone's statement was applicable only if the moment of force of the pure couple had attained a certain magnitude. The different locations of the axis

of tipping of the teeth in the two monkeys can be attributed to circumstances similar to those that confronted the previous investigators and also to problems unique in this experiment. The differences of the contours of the teeth were one of the major factors leading to the different observations of the previous investigators. In this study, monkey IA had a long, curved root with a rounded apex. In contrast, monkey IIIA had a short, straight, and tapered root. Because of the differences in the projected root area of the two roots, it is obvious that different stresses would develop in their respective periodontal ligaments and this then would contribute to the differences in the centers of tipping. In addition, it was mentioned in Chapter IV, that the moment of force for the coil spring in monkey IA was less than that of monkey IIIA. It was assumed in the initial design of the experiment that force magnitudes that were selected would produce optimal tipping movement. This again may have been a contributing factor to the difference between the effective axis of tipping of the two mandibular second premolars on the treatment side.

In relation to the experiment itself, one certainly cannot discount the external factors encountered in any clinical study. One of the most difficult problems was

the final adaptation of the orthodontic appliance. Because the first premolar and the canine teeth were shaped conically, final seating of the bands so that the eyelets would be equidistant from the center of the bracket was difficult to control. Such was the case with monkey IA where the anterior segment of the orthodontic appliance had its eyelet one half millimeter closer to the center of the second premolar than the posterior eyelet; hence, the desired balance of the spring was not fully achieved.

It has been repeatedly pointed out that there is difficulty in applying and maintaining control of a pure couple. Two factors would enhance the maintenance and control of a pure couple by eliminating the adverse extrinsic factors that occurred in this experiment. The experimental results indicated that there was extrusion of the premolar and second molar. In future studies consideration should be given to using a full maxillary arch bite plane to reduce the occlusal interferences and minimize any extrusive action on the part of the posterior teeth. It was impossible to control extrusion of these teeth in this research because the guide plane was on the maxillary anterior teeth. A second suggestion is the placement of full crowns on the conically shaped first premolar and canine teeth to facilitate band adaptation and final seating of the orthodontic appliance.

CHAPTER VII

SUMMARY AND CONCLUSION

A. Summary:

The purpose of this study was to develop a method for the application and control of a pure couple to a posterior tooth of a rhesus monkey and to assess its biophysical effects. A force system was designed to distally tip the crown of the mandibular second premolar. In this study, a predetermined force system was used with calculated force magnitudes and direction. One half of the mandibular arch was used for experimental movement of teeth and the other half was used as a reference side. The mandibular first permanent molars on the treatment and reference sides were extracted. The canine, first premolar, and second molar on each side of the arch served as anchor units. These teeth were taken out of occlusion with the use of a maxillary anterior bite plane.

The appliance designed to deliver the tipping movement consisted of two spiral springs joined at the center and wound concentrically. The terminal ends of the spring were made equal in length. This design was selected because through its stressed coils, two balanced moments of force could be transmitted to the tooth where they

could be expressed as a couple. The spring was fabricated from stainless steel stock, .060 inch wide and .006 inch thick. It was designed to produce a deflection of 45° , and a moment of force of .0398 lb. inch. A cylindrical bracket with an .010 inch horizontal slot was used to secure the spring to the mandibular second premolar. No other brackets were placed on the active or reference side. A load deflection characteristic was made for each spring.

The tipping movement that resulted under the influence of the force system was studied by making linear measurements on roentgenograms. The feasibility of this method was validated with Student's t-test when compared to a method of direct measurement. A stereotaxic instrument was used to position the animal while obtaining the roentgenograms. In addition, orienting devices were used to position the long cone of the x-ray machine. Lateral and occlusal roentgenograms were taken at the first, fourth, eighth, sixteenth, and twenty-third days of the experiment to ascertain changes in tooth position. The precision of the measuring system was calculated from the mean squares of the measurements. From 120 degrees of freedom, the 99% confidence limits of the distribution of experimental error were plus or minus .129 millimeters for the

occlusal roentgenograms. The lateral roentgenograms indicated that the 99% confidence limits were plus or minus .187 millimeters. Therefore, it can be said that the amount of experimental error involved in taking measurements of the lateral and occlusal roentgenograms was very small and was accepted as a practical means of assessing tooth movements. Analytical treatment of data from the rectangular coordinates was the means that was used to check the actual changes of tooth position on the lateral and occlusal roentgenograms.

The physical finding revealed that when a pure couple was applied to the crown of the mandibular second premolar, tipping occurred with the center of tipping located in the root. There was mesial movement of the root apex and distal movement of the crown. The effective axis of tipping was calculated mathematically and found to be 2.65 mm. above the root apex in monkey IA and 2.74 mm. in monkey IIIA. The effective axis of tipping for the two animals was one half the root length of their respective root apices. The roentgenographic findings confirmed the distal tipping movement with changes occurring in the alveolar process. Some extrusion of the posterior teeth also resulted in the experiment. This was attributed to the maxillary anterior bite plane that maintained

the posterior teeth out of occlusion.

These specimens will be studied histologically to further determine the accuracy of the physical assessments.

B. Conclusions:

1. An appliance which develops a nearly pure couple for orthodontic purposes can be successfully designed and constructed.
2. Two of these appliances have verified that they can be designed to produce a predetermined amount of torque.
3. It is possible to achieve very good accuracy and precision in linear measurements made on intra-oral roentgenograms when they are represented in rectangular coordinates and are analyzed mathematically.
4. The rotation of a tooth can be measured on occlusal radiograms if two opaque points are present on the occlusal surface.
5. The tipping of a tooth can be measured on periapical intra-oral radiograms if the root canal is visible and a stable reference structure is visible.
6. The location of the center of tipping can be determined when analytical data from two successive examinations are available. These data must be coordinates of two separated identifiable points in the root, obtained

from lateral periapical roentgenograms.

7. Teeth that are out of occlusion may drift or extrude spontaneously.

8. It is possible to detect and to measure changes occurring in the position of an orthodontically treated tooth during as short a period as seven days.

9. If the desired balance between two halves of the spiral spring is maintained, neither an intrusive nor extrusive force will develop.

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APPENDIX I

DERIVATION OF SPRING DESIGN

1. Assume a working stress in the spring steel to be between 50,000 p.s.i. and 100,000 p.s.i.

Start with

$$75,000 = \frac{6 \times .02}{.060 \times h^2}$$

and solve

for the thickness of the spring strip, h. This yields $h = .00516''$ which is not a readily available thickness. The nearest standard material has a thickness of $.006''$ which will be used. This would yield a working stress of about 56,000 p.s.i. when tested in the above formula which is near the low end of the range.

2. Check the number of turns needed for working and the length of the spring strip that might be reasonably included in the spring.

The activating movement of the spring should be 45° or .125 turns. Insert this information in the formula for turns.

$$.125 = \frac{56,000 \times L}{\pi \times 29,000,000 \times .006}$$

Solving this for L gives $1.220''$ which is too much material to wind into the available space that is only 0.2 in. in diameter (occlusal to gingiva height). The bracket

inside the spring has a diameter of .060" so the mean diameter of the available winding space is about .130 in. A convenient number of turns is nearly 2; we shall assume 1.87 turns.

The calculated length is

$$L = 1.87 \times .130 \times \pi = .76 \text{ in.}$$

This reduced length will increase the stress and this must be calculated.

$$.125 = \frac{S \times .76}{\pi \times 29,000,000 \times .0060}$$

From this $S = 90,000$ p.s.i. This is near the top of the range but is acceptable.

APPROVAL SHEET

The thesis submitted by Dr. Harold Y. Arai has been read and approved by members of the Departments of Anatomy and Oral Biology.

The final copies have been examined by the director of the thesis and the signature which appears below verifies the fact that any necessary changes have been incorporated, and that the thesis is now given final approval with reference to content, form, and mechanical accuracy.

The thesis is therefore accepted in partial fulfillment of the requirements for the Degree of Master of Science.

May 24 - 1966
DATE

Joseph R. Jarabak
Signature of Advisor